POLITECNICO DI MILANO
Process Industry Engineering Class
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Master degree in Materials Engineering and Nanotechnology

FEASIBILITY ANALYSIS OF A WIND TURBINE WITH PHOTOVOLTAIC-PIEZOELECTRIC CARACTERISTICS

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ABSTRACT

The thesis work is part of the research and development of innovative materials for renewable energy and in particular, composites, which in recent years have been receiving special attention from the world of clean energy. During this thesis were studied tensions problems connected with the structural stability of artifacts in the composite fabric and the possibility of realizing a wind turbine with photovoltaic-piezoelectric characteristics. The study developed on three levels: materials research, structural analysis and feasibility of the project. The aim of the thesis focuses primarily on the study of innovative composite materials and the possible applications of these materials. For the purpose of this thesis is to propose a new idea that combines the use of composite materials no longer as simple structure of an artifact, but as an active part of an object. The basic idea taken up by the proposed Renzo Piano adding sections to the structure of composite material with photovoltaic-piezoelectric characteristics, managing to increase the production of energy without neglecting the structural stability of the artifacts in the composite.

The research phase of materials addressed through a literature search that allowed the thesis project to meet a multitude of innovative materials. In particular, the thesis has focused on the possibility of using a photovoltaic-piezoelectric fiber as a functional part of the composite fabric, incorporated in a novel textile called "tetraxial." The positive results obtained from the analysis of the structures considered to have led to propose the design of an innovative composite based on a reinforcement tetraxial combined with a characteristics photovoltaic-piezoelectric fiber, which can act not only as passive part of the wind turbine but especially as active participants. This will provide an additional power source for increasing the efficiency of the wind turbine. Subsequently these proposals and these configurations have been tested and verified, thanks to the support of wind resource survey, based on the study of the wind, which has allowed the study of theory to hypothesize the best placement of the wind turbine. The results obtained from the simulations carried out by means of special interactive maps of the wind are satisfactory. In the future, it is possible to extend the analysis carried out during the thesis work to other facilities to experiment with new materials. The realization of a composite similar to that proposed in the activity of theses could allow the creation of a series of applications that, by exploiting the unusual properties, would have advantageous characteristics under different points of view, compared to conventional composites. During the entire project, has tried to facilitate the possible design stage.

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1. Introduction to composite materials

1.1 General information on composite materials

The main characteristic of composites is the distinct chemical phases: this feature allows us to take advantage from all the properties of its constituents. In recent years, the use of composites has grown significantly, as demonstrated by their functionality in different fields. The success of their application is due to the excellent mechanical properties with respect to their specific weight, durability and versatility, to compete with metals. By the coupling of different materials, the result given from different properties. In such a way, the behavior is better than the properties of individual constituents. This system consists of two or more elements chemically and physically distinct (two main phases such reinforcement and matrix) combined with each other to enhance the unique characteristics of the two components, where the mechanical properties of the reinforcement and the lightness of the matrix define the composite material.

1.2 Classification of composites

Composite materials commonly classified according to two distinct levels:

- The first level usually made with respect to the matrix component. The main classes of organic compounds include organic matrix composites (OMCS), metal matrix composites (MMC) and ceramic matrix composites (CMC). The organic matrix, is a term that is generally assumed to include two classes of composites, that is polymer matrix composite (PMC) and carbon matrix composites;
- The second level refers to the shape of the reinforcement: fiber reinforced composites, composite laminates and composite particle. The fiber reinforced composite (FRP) can be further divided into those containing discontinuous or continuous fibers. FRP composites are composed of fibers embedded in the matrix. This composite may be composed of staple fibers or fibers of varying length. The composite laminates made from layers of material held together by a matrix. For example, the sandwich structures fall into this category. The composite particles are composed of particles distributed within the matrix. For example, cement and wood shavings are examples of this category.

The main advantages of these composite materials are their high strength and stiffness. In most cases, the reinforcement is harder, stronger and stiffer than the matrix. It is usually a fiber. A composite can be characterized by continuous fibers, that defines preferred orientation, or by short fibers, that determines random orientation. The fibers produce high strength composites thanks to their small diameters, in fact smaller is the diameter of the fiber and the greater its strength, but often the cost increases when the diameter becomes smaller. The reinforcements can be of various types: granular, short fiber, long fiber unidirectional or woven. Therefore, the term "composite" indicates a complex set of materials, characterized by different phases that work better together than individually in order to obtain the best performance. The main reason for their great growth is due to the excellent mechanical properties with respect to their specific weight, durability and versatility. The development and study of the composite allow competing with metals. Among the structural materials, fiber-reinforced composites have had an enormous scientific and technological development. The low density, high strength, high stiffness relative to the weight, excellent durability and versatility are the main reasons for their success as structural components in planes, in cars, in space modules, on boats and in many other fields. Combining one or more components, a fiber-reinforced composite obtained fiber and matrix, which in most cases is made of polymeric material. In a composite laminate, the larger volume occupied by the fibers that provide the stiffness and strength. In fact, the amount and orientation of the fibers change the mechanical strength, the mechanisms of fatigue failure, the thermal conductivity and cost. The reinforcing phase (fiber) and the binder one (matrix) give the composite characteristics of orthotropic materials and biphasic. The two phases of the composites is the necessary condition to be orthotropic. Although it is undoubtedly true that the high resistance of the composites is due primarily to the fiber, even if the importance of the material that constitutes the matrix cannot be underestimated because it provides support to the fibers and the fibers helps to distribute loads. Furthermore, it provides stability to the composite material. For example, the resin acts as a binder in a structural component in which the fibers are incorporated.

The correct choice for a matrix dictated by several considerations based on the functions they perform:

- Keep the fibers together;
- Protect the fibers from the environment;
- Distribute equally the load between the fibers so that all the fibers are subjected to the same amount of load;
- Improve the properties of a cross-laminated;
- Improve the impact and fracture resistance of a component;
- Prevent the propagation of a crack through the fibers.

Thanks to the anisotropy of composites that allows arranging the fibers in the direction of the load, the structure optimized. According to the load direction, the fibers can be arranged in several orientations, and by superimposing layers with different fiber orientation, a "laminate" obtained. The mechanical quality, according to the principle of anisotropy for composite materials are very different respect to the geometry of the fibers. This explains the importance in the design phase of a composite, direction and the applied load. However, the properties of anisotropy are advantageous because you cannot use any superfluous material. The engineering theories have shown that the bending stiffness of a laminate is proportional to the cube of its thickness. The possibility of inserting a core between two layers of laminate significantly increases the stiffness of the composite, with a slight increase in weight. This type of composite commonly called "sandwich".

1.3 Structure of composite materials

The blending of two or more components (fiber and matrix) creates a continuous solid material, which is able to transmit and redistribute the internal stresses, due to external stresses, of its components. The composite must also be able to resist to thermal loads, if is subjected to difference temperature, and electric ones when subjected to electromagnetic fields. A classification can be conducted according to the criterion of continuity. In fact, the materials have filamentous dimensional parts, which should be directed, in the directions most convenient to withstand external loads. A second type of classification can be made according to the geometric shape of the structural components: belong the composite honeycomb, very common in the aeronautical field, which require the combination with other materials of stratification and filling. The fibers and the matrix interact: the first provides the properties of mechanical strength and stiffness, while the matrix work as filler between the fibers. Therefore, the matrices are initially viscous fluid state. Subsequently undergo a process of solidification, which allow giving geometric and dimensional stability to the structure. This allows the material to receive the external stresses due to applied loads, redistributing to the fibers in the form of internal stresses. The transmission of stress occurs due to the shear stresses and provided by agreement surface between the two substances in the solid state, due to chemical effects, electrical and mechanical. What happens to the composite under load until the eventual breakage of components, it is not easy to deal with. However, it is possible to give a simplified idea through the microscopic observation of the behavior of a crack, which propagates because of developments in the internal tensions. This interesting initially the matrix, and then propagate through it and reach a number of fibers, causing damage and possible rupture. The behavior of the fibers takes on a crucial role regarding the resistance to external loads, blocking, delaying or favoring the propagation of the crack itself. The strength of the composite, for example, the capacity to oppose the enlargement of the rupture zone, strongly depends on the extension of the contact surface between fiber and matrix. The long fibers reinforcing the composite more than the short fibers, with the same section. Fundamental is the design in advance of the internal geometry of composite, in order to control the possible orientation of the fibers, so in this way they are oriented according to the directions of stress. There are several possibilities of realization of the composite: in relation to the form and arrangement of the fibers. It is possible to use fibers or particulate individual fibers also relatively short and randomly arranged. In such cases, the material has lower characteristics, but also lower costs.

To obtain the desired characteristics of continuity and mechanical strength, it is preferred to bring together the individual fibers in the form of wire. The wires can be woven between them, using different types of weaving according to the functions of the material: biaxial and triaxial. It is possible also, to make fabrics in which the yarns are oriented not only in a plane, but in space, with the yarns oriented in the directions of the maximum stresses. In this way, during the weaving, it is possible to determine both the shape and the thickness of the final section of the resistant composite. Naturally, the costs of production are high. Before the impregnation with the resin in the fluid state, the dry fabrics cut and contoured to the shape and the overall size of the piece to realize. These processes mainly used for fabrics made of carbon fiber, Kevlar and glass. There are also fibrous materials, obtained from metal or ceramic materials, which used not only in the form of wires more or less long, but also in the solid state. These latter consist of monocrystals filamentary lengths of approximately 1 mm, with transverse dimensions of the order of a thousandth of a millimeter. They have internal crystalline structure free from lattice defects and therefore have a high mechanical strength.

1.4 Understanding fibers

1.4.1 Functions of the fibers

Reinforcements in composite materials that increase the mechanical properties, strength and stiffness, may be present individually, concentrated in a bundle (roving) which contains several hundred or twisted (yarn). In general, the properties of the composite depend mainly on the fibers themselves.

The fibers have a different contribution based on:

1 the properties of the fiber itself;
2 the interaction between the surface of the fiber/resin;
3 the amount of fiber in the material;
4 the orientation of the fibers in the composite material.

1.4.2 Types of fibers

It is possible to make a distinction based on the nature of the fibers themselves, which will contribute significantly to the properties of the composite.

Therefore, distinguish:

1 amorphous fibers: mainly glass, and therefore fragile nature, with excellent mechanical strength (2-5 GPa), low cost, good toughness, low elastic modulus (70-80 GPa), medium density (2.5-2.8 g/cm3);
2 polycrystalline fibers: mainly carbon and graphite, with excellent mechanical strength (3.1-4.5 GPa), high cost, low toughness, high elastic modulus (220-800 GPa), low density (1.7-2.1 g/cm3);
3 organic fibers: for example aramid fibers such as Kevlar and Nomex, with very good mechanical strength (3.0-4.5 GPa), high toughness, average cost, average elastic modulus(130-150 GPa), low density (< 1.5 g/cm3);
4 multiphase fibers: such as polyethylene (high specific mechanical properties), aluminum, boron (good compression resistance, high cost).

A further subdivision of the fibers can be made based on the temperature at which they degrade:

1 low temperature (<150 ° C), typical of aramid;
2 intermediate temperature (150-400 ° C), typical of boron and glass;
3 average temperature (400-700 ° C), for metal fibers;
4 high temperature (> 700 ° C), for graphite fibers and ceramics.

Finally, the fibers can be distinguished according to the couplings in the compounds multifilament:

1 wires: are constituted by one or more wires;
2 roving: consists of parallel fibers and wrapped in coils;
3 mats: obtained by weaving the roving.

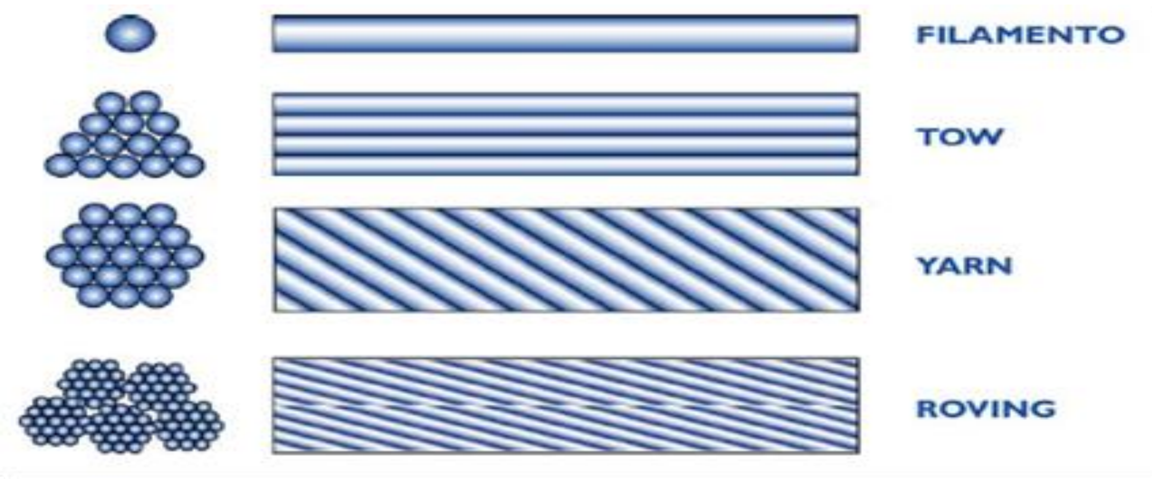

Figure 1: Types of fibers

The qualities of strength and stiffness of a composite material, are given by the fibers or "filament", or a structure element elongated, with longitudinal dimensions much greater than the diameter (approximately 10mm). By combining multi-filament bundles in parallel, you get the so-called "tow". A tow twisted, when you get the "yarn". In the textile, part of the fibers are relatively straight (warp) and part are crimped (weft). Therefore, the fabric is stronger in the warp direction than in the other directions.

Some examples of fibers used as reinforcement:

Glass fibers (Fiberglass): mainly used in the marine industry are distinguished for their high tensile strength and low cost (varies from 2400 MPa to 3500 MPa). The glass fibers are available in thin sheets called "mat" or in the form of roving. A mat, shown in Figure 2, can be composed of both long fibers and continuous that short fibers arranged randomly in the plane.

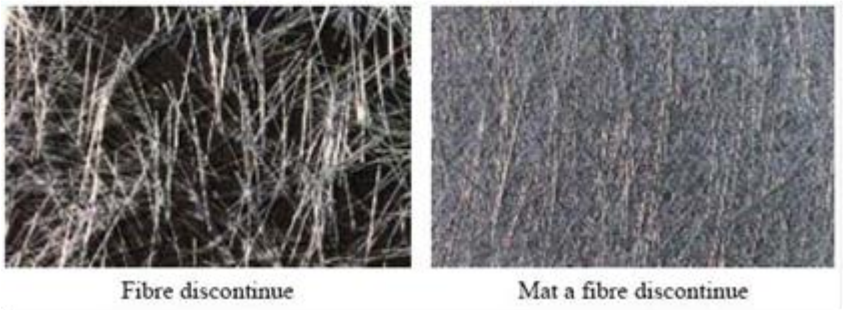

Figure 2: Mat in fiberglass

Carbon fiber (Carbon Fiber): used for high performance composites are characterized by a high modulus of elasticity (varies from 150 GPa to 850 GPa) and high resistance (between 1900 MPa and 3200 MPa). Consist of graphite planes oriented in the longitudinal direction, are obtained by pyrolysis of organic precursors, of which the most common are polyacrylonitrile (PAN), rayon and pitch. The carbon fibers have a modulus of elasticity much higher than that of the glass fibers, a resistance which can be more than 10 times that of steel and a density between 1.7 and 1.9 kg/dm3. (Roberto Frassine; Materiali Compositi XXI (2010))

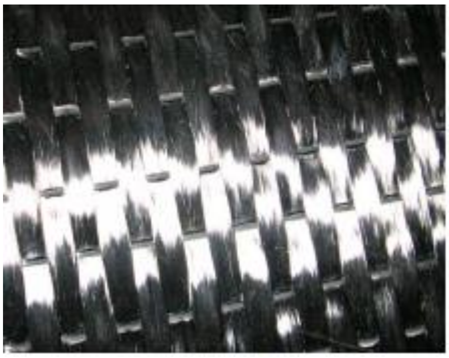

Figure 3: Unidirectional carbon fiber

Aramid fibers: fibers are organic in nature consisting of aromatic polyamides, characterized by high toughness and easily manipulated. The fibers produced by extrusion at high temperature and high speed of the polymer with subsequent rapid cooling and drying. Are commercially available in the form of yarn, roving and fabrics. Produced for the first time in 1973, by the DuPont, under the trade name Kevlar.

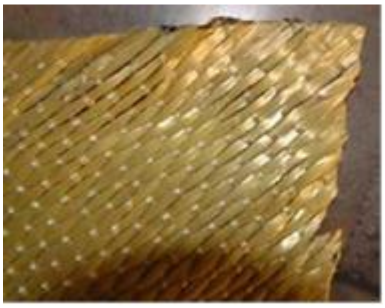

Figure 4: Unidirectional aramid fiber

For the manufacture of materials of synthetic nature are employed particularly those based on polyvinyl alcohol (PVA), polyethylene (PE) and polypropylene (PP). In recent years, it has also witnessed a progressively increasing use of natural reinforcing fibers, such as, fibers, hemp and flax. (Roberto Frassine; Materiali Compositi XXI (2010))

1.5 Matrix’s fundamentals

1.5.1 Functions of matrices

The realization of a composite material always passes through a process of impregnation of the dispersed phase reinforced, in order to get a continuous phase.

The matrix within a composite material:

1 functions as the link between the fibers;
2 keeps the fibers separated;
3 protects the fibers from the surrounding environment;
4 prevent any cracks in the fibers arising from spreading.

The matrix, in a composite structure, has a secondary role in the ability to tolerate a load, while it has a great influence on the interlaminar shear. The interlaminar shear strength is an important consideration in the design of structures subjected to bending loads, while the shear strength in the plane is important in the presence of torsional loads. The matrix provides lateral support against the possibility of deformation of the fiber under the action of a compressive load, thus affecting a certain resistance of the composite material. Finally, defects in a composite material depend strongly on the physical characteristics and thermal properties, such as viscosity, melting point, and temperature of the matrix.

The choice of material for the matrix must be made under certain consideration:

- the matrix must have a mechanical resistance commensurate with the reinforcement;
- the matrix must withstand the conditions of service, namely: temperature, humidity, exposure to ambient radiation, exposure to chemical atmosphere, abrasion by dust particles, etc.;
- the matrix selected must be easy to use in the manufacturing process;
- long life expectancy;
- the resulting composite has to be affordable.

The polymer matrix composites (PMCs) are characterized by a variety of short fibers or continuous, linked by an organic polymeric matrix. Unlike a ceramic matrix composite (CMC), in which the reinforcement is primarily used to prove the fracture strength, the reinforcement in a PMC provides high strength and stiffness. The PMC designed so that the mechanical stresses of the structure subject to service shall be accepted by the reinforcement. The function of the matrix is to bind the fibers together. Polymer matrix composites often divided into two categories: reinforced plastics, and advanced composites. The distinction based on the mechanical properties (strength and stiffness). The "reinforced plastic", are relatively inexpensive, typically consisting of polyester resins reinforced with glass fibers with low rigidity. While "advanced composites", have superior strength and stiffness, and are relatively expensive. The properties of the matrix determine the resistance of the PMC for most of the degradation processes that eventually can cause the collapse of the structure. These processes include bumps, delamination, water absorption and chemical attacks. Therefore, the matrix is usually the weak link in the structure of the PMC. It can make a distinction of the matrix, based on the maximum value of the temperature used. Also, can be divided into organic (or polymer) and non-organic. Organic ones are the most widespread both for their versatility of application and costs. The organics divided into thermosets, thermoplastics and bio-matrices, while the non-organic into metal, ceramic and vitreous.

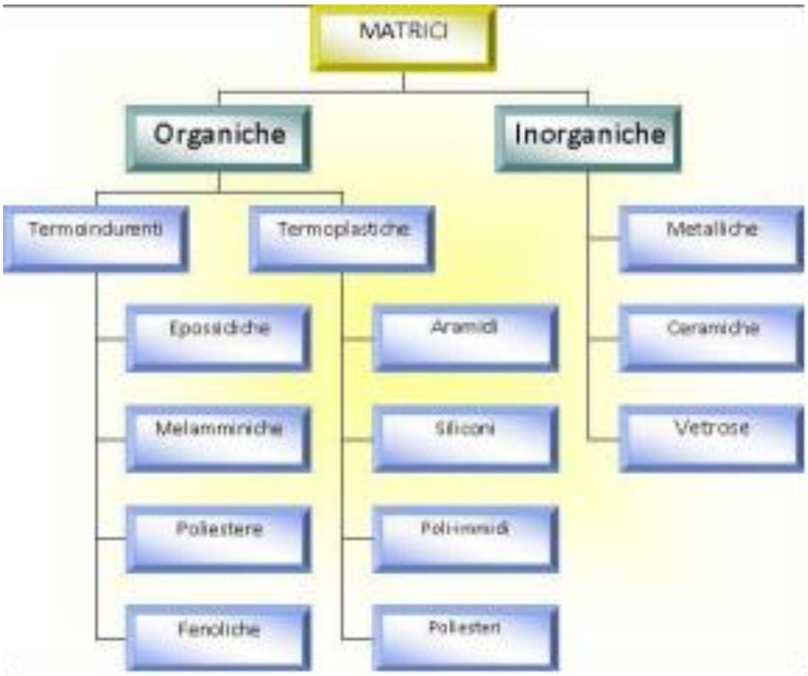

Figure 5: Matrix classification

For example, thermoset resins include polyesters, vinyl esters, epoxy resins and polyamides. Thermoset polyesters commonly used in fiber-reinforced plastics. Initially, the viscosity of these resins is low, thermoset resins undergo chemical reactions that change the reticular structure of the polymer chain, and then connect the entire matrix to a three-dimensional network. This process called polymerization. "Thermoset", because of their three-dimensional cross-linked structure, tend to have a high dimensional stability, high temperature resistance and good resistance to solvents. This resins are most commonly manufactured and sold in solution with water or alcohol (methanol or butanol), and are referred to as "polymer solution" or "resins solution", but can be produced and sold as solids. Often resins appear as a clear liquid (low viscosity) or quite thick (high viscosity). Thermoset resins are water-based in order to obtain lower costs and lower volatile organic components (VOCs). To understand these resins and the best way to select and use them is useful to understand some aspects of the chemistry involved in these resins and how work. The molecules contained in these resins do not form a polymer chain; the molecule of formaldehyde used to react and to form a long chain molecule or "polymer" that can be used as a resin or binder to form a methyl group. This methyl group becomes an attractive reaction site, which is capable of "condensation reactions" to bind the molecules together in a polymer chain (polymer) or matrix structure.

The most used are:

- epoxy resins (for T <250 ° C);
- polyester resins, characterized by a low cost;
- phenolic resins, (for T > 250 ° C).

The most common, phenolic resins, were the first used in aircraft applications. These resins show good resistance to solvents and water vapor. They have the property of becoming insoluble after been brought melted and then cooled. This derived from the formation of a three-dimensional lattice, at the molecular level, held together by strong covalent bonds that make the process irreversible. Phenolic resins are among the most popular condensation polymers. They are useful in wide range of applications such as thermal and acoustic insulation, molding compounds, and composite products. The economic importance of phenolic resins shows that they are irreplaceable in various fields of engineering. Phenolic resins usually made by condensation polymerization of phenol and formaldehyde, which gives them another name, phenol formaldehyde based resins. However, they were unknown as a commercial product until a patent granted to Leo H. Baekeland in 1909.

In general, the phenolic resin is rigid in structure due to its bulky benzene rings, and fragile because of the gaps between the benzene rings. Therefore, the use of phenolic resins have limited use in applications. Phenolic resin exists in two types: resole and novolac. Phenolic resins are relatively stable until about 200 °C; above this temperature, the carbonization is more rapid.

Thermoset resins benefits:

- low cost;
- properties of high strength;
- usually highly diluted.

Thermoset resins disadvantages:

- non-flexible, hard;
- restrictions storage at room temperature;
- need polymerization at high temperature;
- formaldehyde emissions.

The "polyester resin" is an important matrix resin for thermosetting polymer composite. Polyester does not constitute the largest group among the commercial synthetic polymers. However, for their range of applications, enjoy a leadership position, in fact are widely used in a number of applications, in which the advantage can be taken into account for their good range of mechanical properties, low cost, good resistance to corrosion and low weight. Polyester resins have also been used for coatings, fillers bodies, work surfaces (such as marble, polyester) concrete (for applications such as road drainage), wallboard, sheeting, tiles, pipes and also for applications such as bathroom furniture (for example bath tubs and shower trays). However, products of unsaturated polyester resins are still limited due to the low chemical resistance compared to the cost of the epoxy resin. This is because the unsaturated polyester resins have a low hydrolytic stability, and at the same time have little control over the rate of reaction. Therefore, through chemical and physical changes, it was possible to use new materials such as polyester resins in paints.

The "epoxy resins" are resins containing more than one epoxy group can be converted in the form of polyester. These resins, with the polymerization, do not create volatile products despite the presence of a volatile liquid solvent. The hardening of the epoxy group takes place both between the epoxy molecules themselves or by the reaction between the epoxy group and other reactive molecules with or without the aid of the catalyst. Epoxy resins have good insulation properties and particularly used in the process of "potting", as well as in fusion. The versatile properties of epoxy resins make them valuable as adhesives in civil and military applications. Adhesives based on epoxy resins are available as liquids bicomponent, thermosetting liquids, powders, films and tapes. The adhesive formulation based on epoxy resins requires a great variety of polymerization and modifying agents. Their fracture behavior is brittle, but their toughness can be increased significantly with the addition of rubber particles. The maximum operating temperature can reach up to 180 °C approximately. The coatings industry is the largest consumer of epoxy resins. These resins used primarily as special coatings. Epoxy resins provide a thin layer of durable coating having mechanical strength and good adhesion to a variety of substrates. They are resistant to chemicals and corrosion. They find applications in washing machines, ships and bridges, pipelines and chemical plants, automobiles, and floor coverings.

The "polyamide resins" belong to an important class of polymers for their glass transition temperatures and an excellent thermal stability. These properties make them ideal for use in high temperature applications, both as a pure polymer or as a matrix for polymer matrix composites (PMC). For the modeling and design of polyamide, it is important to know the properties of moisture diffusion, since the absorbed moisture can affect the mechanical properties. The inherent limitations of thermosetting resins, in particular the lack of toughness, the maximum operating temperatures rather modest and the tendency to absorb moisture from the environment, have led in recent years to the development of thermoplastic matrix composites. Thermoplastic resins are generally more tenacious and can be used at higher temperatures compared to thermoset resins.

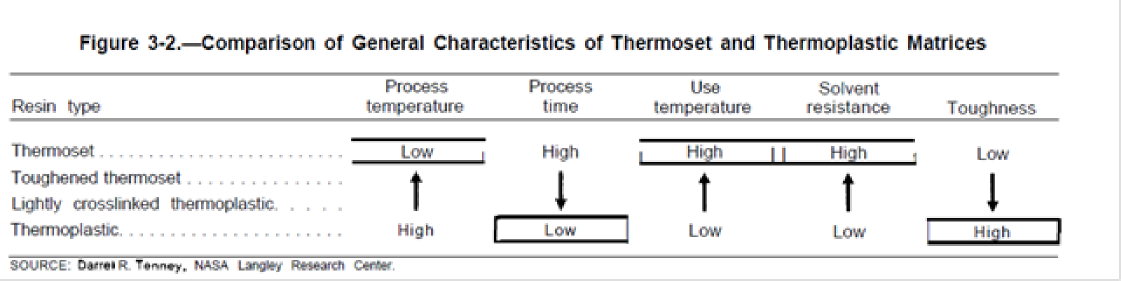

Figure 3-2.—Comparison of General Characteristics of Thermoset and Thermoplastic Matrices

Resin type	Process temperature	Process time	Use temperature	Solvent resistance	Toughness
Thermoset	Low	High	High	High	Low
Toughened thermoset	↑	↓	↑	↑	↓
Lightly crosslinked thermoplastic					
Thermoplastic	High	Low	Low	Low	High

SOURCE: Darrel R. Tenney, NASA Langley Research Center.

Figure 6: Comparison of general characteristics of thermoset and thermoplastic matrices

The "thermoplastics", sometimes called "engineering plastics" include some polyester, polyimide, and liquid crystal.

Thermoplastic polymers divided into:

- amorphous polymers;
- semi-crystalline polymers.

They consist of long molecules that come together in a viscous liquid to processing temperature, and, after forming, cooled in an amorphous, semi crystalline or crystalline solid. The degree of crystallinity has a strong effect on the final properties of the matrix. Unlike the process of polymerization of thermoplastics is reversible, and, by simply heating the temperature of the process, the resin can be formed in another shape. The thermoplastic, although generally lower resistance than the "thermoset" at high temperatures, are more resistant to cracking and to damage from impact. Have been recently developed high performance thermoplastic resins, such as PEEK[1], which have a microstructure of semi-crystalline, which shows excellent high temperature and solvent resistant and offer great promise for the future from a production point of view, as is faster and easier to heat and cool. This makes it attractive for the thermoplastic matrix’s automotive industries. Currently, thermoplastics used primarily with discontinuous fiber reinforcements, such as glass or carbon. However, there is a great potential for high performance thermoplastic reinforced with continuous fibers. (Roberto Frassine; Materiali Compositi XXI (2010))

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[1] Polyether ether ketone (PEEK) is a colorless organic polymer thermoplastic in the polyaryletherketone (PAEK) family, used in engineering applications.

1.6 Fields of application

In recent years has increased the use of composites. An example is the progressive use in the construction field. An ever more important for the excellent mechanical properties, durability and versatility, to compete with metals. The fiber-reinforced composites, including structural materials, have had an enormous scientific and technological development. The fibers occupy the volume fraction greater in a composite laminate providing stiffness and resistance to it. It is very important to select carefully the type, amount and orientation of the fibers because this affect the following features of a composite laminate:

1 relative density;
2 mechanical strength and elastic modulus;
3 mechanisms of resistance and fatigue failure;
4 thermal and electrical conductivity;
5 cost.

The role of the matrix in a fiber-reinforced composite is to:

1 transfer the tensions between the fibers;
2 protect the fibers from the corrosive environment;
3 protect the surface of the fibers from mechanical abrasion;
4 create internal tensions that pack together the fibers and prevent it from buckling caused by a compression load;
5 transmit the shear interlaminar (flexural load) and in the plane (torsional loads).

The advantages of composites

A summary of significant advantages exhibited by composite materials are:

- high resistance to fatigue and corrosion degradation;
- due to increased reliability, there are fewer checks and structural repairs;
- better resistance to bruising;
- high impact resistance;
- composites are dimensionally stable for example have low thermal conductivity and low thermal expansion coefficient. The composite materials can be tailored to meet a variety of requirements;
- construction and installation are simplified, thus reducing costs;
- improved weather resistance of composites in the marine environment, as well as their resistance to corrosion and reduction of maintenance time;
- improved friction and wear resistance.

The disadvantages of composites

Some of the disadvantages are associated with composites; others associated with the production process and in relation to the technology used will also vary defects:

- high cost of raw materials and workmanship;
- the composites are more brittle than metals worked;
- re-use and can be difficult;
- anomalous arrangement of the fibers;
- breakage of the fibers;
- uneven distribution of the matrix.

Some defects can be solved by discarding the defective part, while the technological defects due to the irregular distribution of the matrix, can be reduced by modifying in a suitable way the technological process of production. Composite materials have a high potential for application in the automotive engineering, for engine parts (valves, piston, piston pin, cylinder head cover, crankshaft, bearings, and engine block). In the aviation industry the high specific strength, high Young's modulus, the small thermal expansion coefficient, the resistance and high conductivity has a particular interest.

Composites are products, which are characterized by an exceptional structural strength, rigidity, excellent resistance to corrosion and at the same time extraordinary lightness. In fact composites are used for applications in various industrial fields, and through a variety of processing technologies in continuous fiber composite materials such as stratification (also known as lamination), winding (FW, Filament Winding), pultrusion, resin transfer molding (RTM resin Transfer Molding), resin infusion vacuum and compression molding of semi-structural components with discontinuous fibers, that find applications in the most various industrial fields.

In the textile industry:

- Rollers;
- Plates and profiles.

Mechanical, petrochemical:

- In the field of mechanical automation (electronic, automatic machines, biomedical, robotics), and petrochemical industries;
- Pipes and pressure vessels (as an alternative to stainless steel).

Nautical:

- Rudders;
- Booms, masts, bowsprit and spinnaker poles;
- Awnings for sailing boats.

Sport:

- Paddles and accessories for canoes and kayaks;
- Details of bicycle frames;
- Skates;
- Insoles for shoes for trekking, rock , cycling;
- Protections for motorcycle boots;
- shin guards for skiers/players.

Furniture:

- Design furniture, chaise longue;
- Veneer sheets;
- Lamps.

Doctor, Orthopedics:

- Special wheelchairs for disabled;
- Plates for X-ray machines.

Eyewear, Jewelry:

- Watch components;
- Straps;
- Jewelry.

Automotive:

- Rims for cars and bikes;
- Silencers for motorcycles and mopeds;
- Accessories for indoor and outdoor.

Renewable Energy:

- wind turbines and wind turbine structures, lighter and more durable if made of carbon fiber, therefore more efficient.

Aeronautical:

- Pipes for aeronautical applications;
- Details of the mold;
- Frames for ultra-light planes.

These are just examples of application fields. From now, it will be possible to describe in detail some of the fields listed above.

1.6.1 The use of composites in the aircraft industry

The use of composite materials in aeronautics has spread more and more in recent years. The basic requirements of aircraft construction are lightweight, strength and stiffness. The composite materials perfectly meet these specifications, although the matrix phase tends to lower these properties. The BELL/BOING V22 Osprey is an example of aircraft built towards the end of the decade, almost entirely in the composite.

The most common applications, developed on board aircraft, include:

- cowlings;
- control surfaces;
- landing gear doors;
- interior cabin.

Some primary structures of the Boeing 777 or military aircraft such as the Harrier II AV8B have made entirely the wings in composite. The polymer matrix composites reinforced by fibers mainly used for the extreme lightness and high specific strength. The use in aircraft engines is now limited by the resistance in the temperature (about 200 °C for epoxy resins), but the use is increasing rapidly. In total, the composite materials currently represent 5% of the weight of an aircraft engine. In the aeronautical composite materials are widely used mainly due to the combined weight savings, without lose high fatigue strength, and corrosion resistance. In Figure 7 are highlighted parts of an aircraft in which it used more composite materials, parts of the wings and tails, fuselage, landing gear, seats, floors, interior panels, tanks, helicopter blades (Figure 8). In particular for the realization of the panels and floors are used sandwich structures with core honeycomb aluminum (Nomex) and skins in carbon or Kevlar; skins for aircraft hybrid structures are used in aluminum and glass fibers (Glare, Figure 9) or laminated carbon fiber with epoxy resin. The major disadvantage of these materials is especially the high costs of production. In fact, the processes used for the production of the elements of a plane characterized by low automation and use of manual techniques that require long production times and a high use of human resources. The most common process is the lamination in the autoclave with vacuum bag (bag molding), in which use of prepreg[2] of carbon fiber in epoxy resin in a closed autoclave (reinforcements also used in glass fiber or Kevlar).

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[2] Pre-preg is a term for "pre-impregnated" composite fibers where a matrix material, such as epoxy, is already present.

After manually superimposed prepregs, according to a precise sequence of lamination, linked to the design features of the finished piece, it submits the artifact, kept under vacuum in a bag, in a particular cycle of pressure and temperature in an autoclave. The low production volumes and high performance requirements justify the use of this technology. (M. Luigi Torre, Barbara Cera, Josè M. Kenny; Il ruolo dei materiali compositi nel settore automobilistico, aeronautico e aerospaziale)

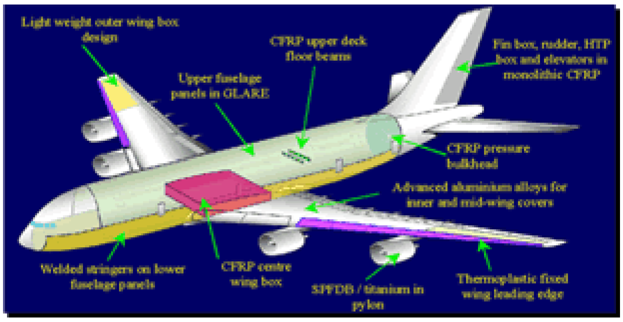

Figure 7: Parts of Aircraft

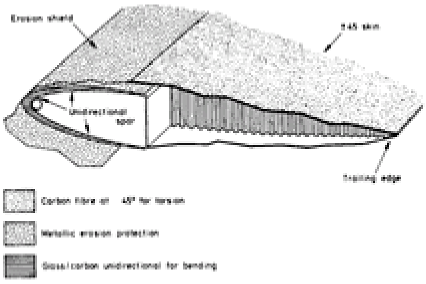

Figure 8: Helicopter blades

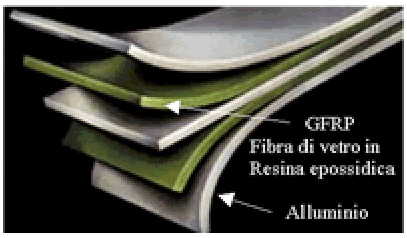

Figure 9: Glare

The polymer matrix composites used for extreme lightweight and high specific strength in the aviation industry. Overall, the composite materials currently account for 5% of the weight of the engine, due to savings in weight. The parts of an aircraft in which you use more composite materials are parts of the wings and tails, fuselage, landing gear, seats, floors, interior panels, tanks, helicopter blades. The disadvantageous aspect especially linked to the high costs of production. In fact, the processes used for the production of the elements of a plane characterized by low automation and use of manual techniques that require long production times and a high use of human resources. The use of composite materials, in civil aviation, applied to parts of the primary structure makes possible a significant reductions in weight maintain structural performance. These materials, however, are not efficient from the acoustics point of view, resulting in a sharp decline of the level of comfort. In this scenery, the research project ARCA ("Ottimizzazione delle caratteristiche Acustiche di mateRiali Compositi per l'Aeronautica"), aims to develop innovative composite materials with improved acoustic properties compared to conventional composites, ensuring the mechanical and structural requirements.

The types of change in the material investigated are:

- The insertion of a layer of damping material ("damping layer") within the different layers of which the composite material is formed;
- The addition of fiber damping material inside the individual layers of the composite;
- The addition of nanomaterial at the level of the matrix and/or fiber.

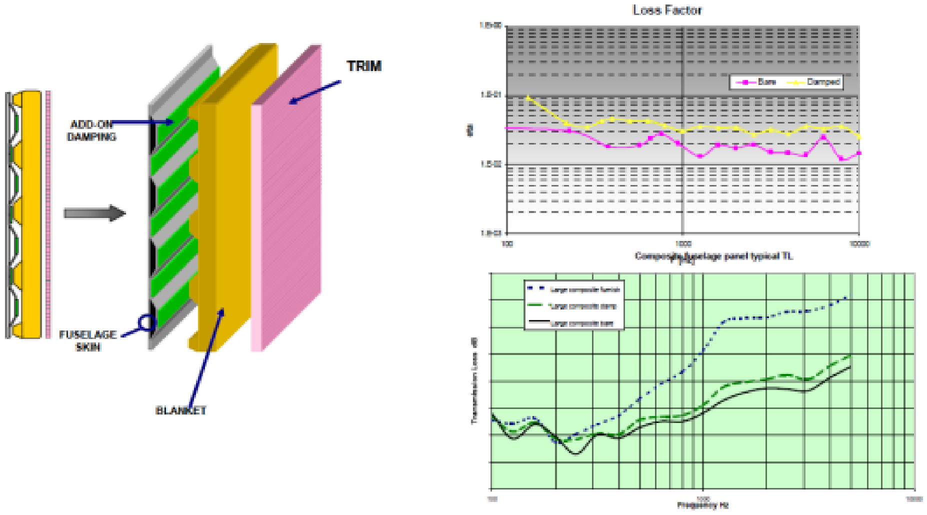

Figure 10: Results of ARCA's project

1.6.2 The use of composites in the field of construction

In the field of construction, the use of composite covers mainly three areas of application:

1 *External reinforcement of existing structural elements of various types and material*;
2 *Internal framework of traditional materials such as concrete, masonry and wood*;
3 *All-composite structure*.

The reinforcement for deteriorated or damaged structure covers the greater number of applications. The advantages that led to its widespread use are:

- The rapidity of interventions;
- Good efficiency;
- The relatively low cost.

Mainly used to increase the shear strength of structural elements such as beams, columns and pillars. Significantly, the high ratio "strength/weight" is need for structures subjected to seismic actions where the masses are crucial. In this technology wraps (bandage) with composite is a true revolution in structural engineering. In fact, the confinement of the columns represented in Figure 11, obtained with simplicity and efficiency by "plating" the structural elements with fibers or fabrics impregnated with resin. The results show increments in terms of the load. (Luca sgarito; analisi sperimentali degli effetti della temperatura elevata su comportamento strutturale dei rinforzi FRP)

Figure 11: Example of column wrapped to increase the bearing capacity

In the second category are used bars and wire obtained with various technology. These used to arm beams and walls of concrete or masonry. The bars in composite material replacing the normal steel bars is a widespread practice in many countries of the world. In this regard shown in Figure 12 an example of application of the bars.

Figure 12: Bars in a bridge

In the third category are used pultruded profiles, of which an image shown in Figure 13: light, strong and stiff enough. These materials typically act as a supporting structure for the frame.

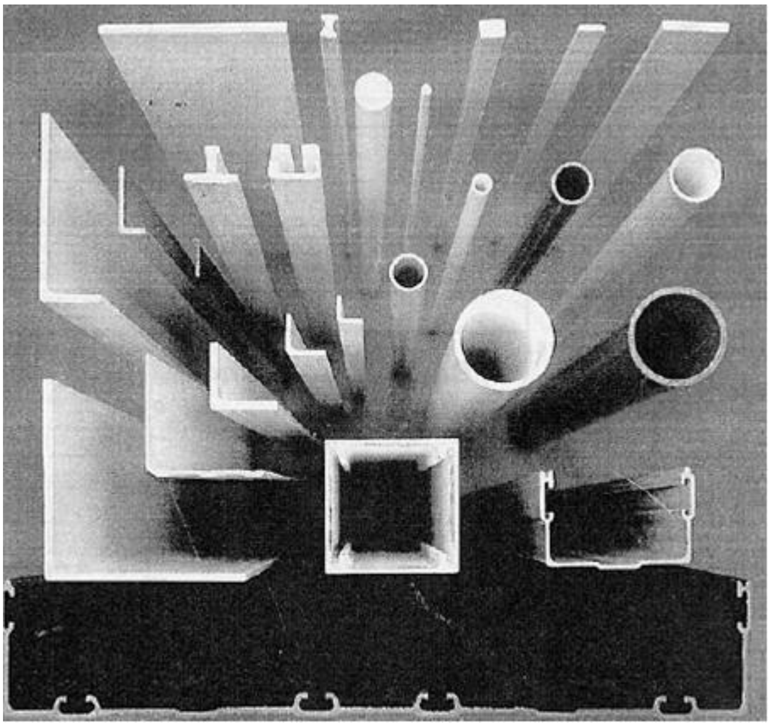

Figure 13: Pultruded profiles

1.6.3 The use of composites in the aerospace industry

The aerospace sector is the largest sector of the aviation industry in which are used composites. In this sector, in many cases, is not suitable any other type of material, both for reasons of weight and for thermal variations. The weight reduction is the main reason for the use of fiber-reinforced composites in many aerospace vehicles. Space Shuttle, for example, the total savings in weight is due to the use of fiber-reinforced composite, which is 1200 kg. It is often associated, the composites, with aerospace applications systems for their high stiffness and excellent thermal stability: many laminates epoxy resin reinforced with carbon fiber can be designed to obtain a coefficient of thermal expansion close to zero. (M. Luigi Torre, Barbara Cera, Josè M. Kenny; Il ruolo dei materiali compositi nel settore automobilistico, aeronautico e aerospaziale)

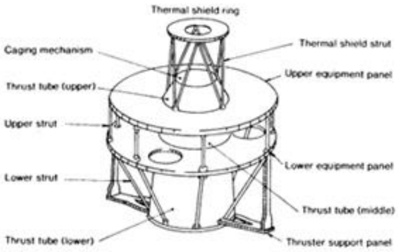

Figure 14: Satellite (on the left)

Figure 15: Typical structure in epoxy resin and carbon fiber of a communications satellite

1.6.4 The use of composites in the automotive industry

The use of composites in the automotive industry can achieve several advantages from the mechanical point of view, technological and environmental. The matrices used in the automotive field are made of polymeric type, and characterized by a very low density giving lightness to the component, while the reinforcements are in glass fibers, carbon or natural, and therefore give good properties to the final structure.

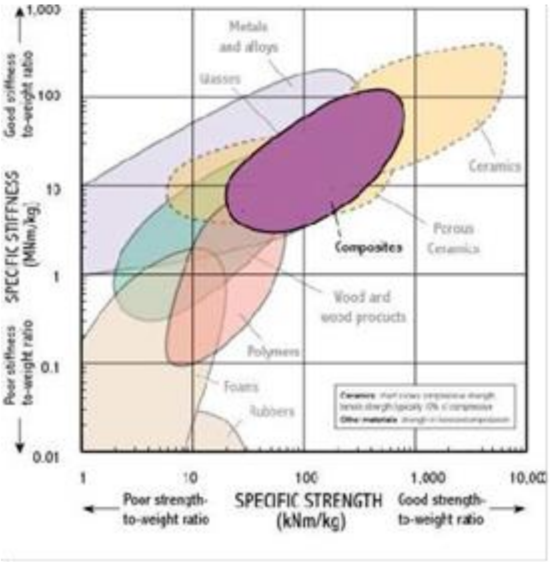

Figure 16: Specific resistance-specific stiffness for different materials

Indeed, the composite materials are used in the interior and bodywork parts (not subject to strong loads), but also in the shells (principally subject to torsion) and in some transmission components such as gear wheels or shafts (primarily subject to fatigue).

From the technological point of view, they have several advantages:

- the production of composite material is much faster than that of metallic materials;
- composites do not require heat treatment;
- additional benefits in assembly cost;
- the production of composites requires less energy compared to metallic materials.

The most commonly fiber used in structural applications in automotive is the glass fiber (E-glass fibers). As regards the resins in this field dominate, in particular the polyester and acrylic. The high-performance materials such as carbon fibers and epoxy resins used only for structural applications. (M. Luigi Torre, Barbara Cera, Josè M. Kenny; Il ruolo dei materiali compositi nel settore automobilistico, aeronautico e aerospaziale)

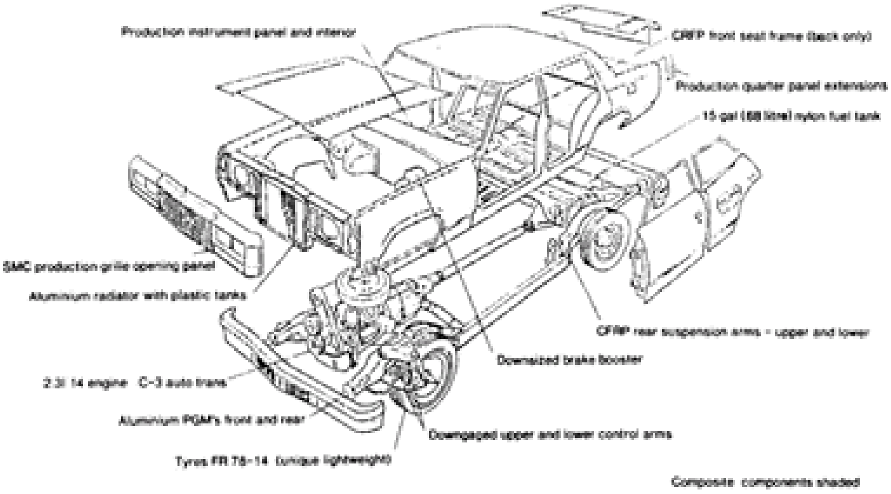

Figure 17: Composite parts of a car

1.6.5 The use of composites in the marine industry

The use of fiberglass has allowed researchers and manufacturers to develop technologies and materials that are more versatile, even for boating. The introduction of advanced composite (such as "sandwich") was an innovation compared to the simple composite (with fiber), which allowed to obtain boats more rigid and lighter, with evident benefits both in navigation and in service life. There are various types of construction using composite materials. The first is the union of resin and fiber (fiber filled) with which they are currently produced almost all of the shell of series boats.

Figure 18: With the use of advanced composites have been able to achieve the shell of large dimensions, greatly reducing the weight and increasing the stiffness

Today the most common composite materials can be collected into three different categories:

- polymer matrix (PMC) composites are the most common and known as FRP (fiber-reinforced polymer). These materials employ a polymeric resin as a matrix and as reinforcement use different fibers such as glass fiber, aramid fiber (Kevlar) and the carbon fiber. These composites are those used in marine construction;
- metal matrix (MMC): where the matrix is a metal and the reinforcement is composed of fibers such as silicon carbide. These composites are mainly used in the automotive industry;
- matrix ceramic (CMC): use ceramics as the matrix and short fibers as reinforcement or bristle, such as those derived from the silicon carbide or boron nitride.

The polymer matrix composite materials are the most used in the shipbuilding world industry to achieve hulls, blankets and structures of both motor boats and sailing. The resins, processed and used individually (without being coupled to any other material) used in the manufacture of small structures, because of the limited mechanical characteristics. They keep some advantageous qualities such as the ability to adapt easily to complex shapes. Materials such as glass, aramid and carbon have a high resistance in tension and in compression, but in "solid form”, these properties are not so obvious. This is because, under conditions of stress, surface defects lead to cracking and breakage much below the theoretical "break point". To overcome this problem, the material manufactured with fibers so that, in presence of a number of defects, these will be confined only to a limited number of fibers, thus keeping valid the theoretical strength of the material. It is to be remembered, however, that the fibers are resistant in tension only in the direction of the length. By combining resins with reinforcing fibers of glass, carbon and aramid, you get the best performance of the material. The matrix (resin) distributes the load applied to the material (fiber); protects the latter from damage caused by abrasion and impact shock. The quality obtained with PMC are the result of the fusion of the properties of individual elements.

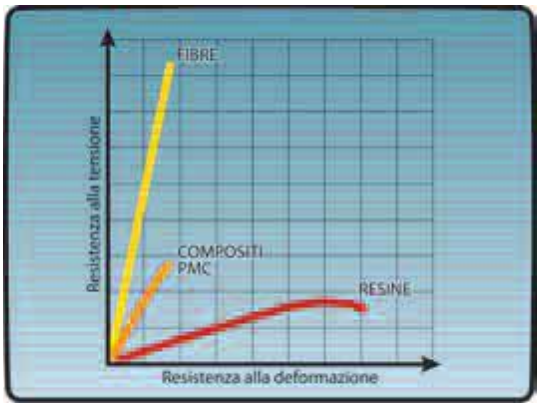

Fig. 19: The graph shows the mechanical qualities of the fibers and resin, and the average when are combined as a simple composite

Fig. 20: Three types of "mats", from left: glass fiber, carbon fiber and Kevlar fiber

In general, the properties of the composite materials determined by four fundamental rules:

1. the properties of fibers;
2. the properties of resins;
3. the ratio fiber/resin (FVF);
4. the orientation of fibers.

All the fibers used in the composite have different roles: good mechanical properties, high level of adhesion, hardness and resistance to environmental degradation. This type of resins are generally: polyester, vinyl ester and epoxy. The polyester is the most used in the processing of the composite and especially in the marine industry. The majority of boats made with these resins. The vinyl ester is similar to the polyester, but is much more shock resistant and therefore more resistant. Another feature of the vinyl ester is the most resistance to water and chemical agents, so that very often used for the production of pipes and tanks. The epoxy resin is superior to the other resins described above, in terms of better mechanical characteristics and resistance to environmental agents, which commonly used in aerospace applications. This epoxy normally used in building high-performance boat.

2. Renewable energy and innovative materials

Thanks to the development of new fibers and new resins, it has developed a progressive diversification of applications. A great use of composite materials is in renewable energy field. These are the main materials used in the construction of large wind turbines. The most common type of composite is fiberglass, but the increase in size (especially for offshore installations) make necessary the use of super fibers, such as carbon and aramid. The research is constantly forcing to provide new solutions that ensure a better balance between their technological performance and environmental compatibility. Technological progress has nearly doubled the overall energy consumption. It requires a new approach to energy production that focuses greater attention on renewable energy research and innovative processes for energy conversion. The optimization of processes and architectures will help to increase the performance of the devices existing power generators both in terms of conversion efficiency and in terms of increased life times and reduction of production costs. The application of these devices, both National and European, favoring the production of energy from renewable sources (for example, solar radiation or electromagnetic radiation), reducing emissions of CO2 and other polluting gases and reducing fuel consumption in combustion processes (for example, heat recovery of exhaust gas vehicles).

Materials and thermoelectric modules for heat recovery

The internal combustion vehicles (about 30-35%) by the chemical energy present in the fuel is lost in the form of heat of the exhaust gas: the possibility to transform such heat in a form of valuable energy (electrical or mechanical) and usable on board vehicle, would radically reduce fuel consumption and pollutant emissions and CO2. The thermoelectric (TE) is a technology that allows the direct conversion of thermal energy into electricity through solid-state devices, inorganic, high temperature resistant, ensuring long lifetime and no maintenance. The great technological challenge for the coming years will be to produce thermoelectric materials in large quantities and at low cost, by the synthesis of nanopowders of TE materials. The low-cost methods (chemical synthesis, mechanical milling, etc.) and their subsequent sintering in macroscopic samples by Spark Plasma Sintering[3], give a significant impact for both economic and environmental aspect.

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[3] Spark plasma sintering (SPS), also known as field assisted sintering technique (FAST) or pulsed electric current sintering (PECS), is a sintering technique.

Lithium batteries and fuel cells

The use of lithium-ion batteries based on lithium iron phosphate cathodes and electrolytes based on ionic liquids, will achieve safe and easily recyclable batteries. This will allow both the production of hybrid electric urban vehicles with good performance and high security.

Gas storage in the solid phase (methane and hydrogen)

Gas storage on board the vehicle to power internal combustion engines (methane, hydro- methane) or fuel cell systems (hydrogen) is currently a high-pressure composite tanks (currently 200 bar, but is facing applications to 700 bar). Such systems characterized by high cost and considerable weights. An interesting alternative from the safety point of view is the application of nano-structured materials for the absorption of the combustible gases will produce pressure tanks for gas powered vehicles and fuel cell vehicles characterized by low pressure, low cost and conformability.

Solar Botanic

From economic and ecological interest especially for materials that need a recycle like material composites, such as particles, short fibers or continuous reinforcing fibers of metal, the Solar Botanic expects the realization of artificial trees for the production of energy. The Solar Botanic is making use of thermoplastic materials, with high-quality renewable resources. There are ribbons of piezoelectric react to a multitude of forces, tension, compression, bending, shear, torsion (movement). A strong and reliable material that can provide additional energy output, which ensures no loss during a storm.

New composite for solar cells, derived from pyrite

Researchers from Oregon State University, through extensive studies have evaluated the quality of the "pyrite", already known to the ancient Romans to discover new compounds that offer new options. These, unlike some expensive materials or toxic, can be derived from some of the most abundant elements on the Earth. The results of research on them have been published in the scientific journal Advanced Energy specialist. The pyrite may certainly use for its energy absorption capacity, and be used in much thinner layers of many other materials.

Marine current turbines

One of the objectives of the renewable energy is to seek balanced solutions for the environment. The issues that are of concern and where attention focused, are the energy dependence and the relative security of supply and the other the issue of global warming. Especially, the attention directed to an alternative source of energy that generated by ocean currents, with water masses in motion due to the difference of the thermal gradient of the water, currents and undertow of drift, tides, wind etc. This energy can be exploited using special turbines able to converting the kinetic energy of the water into mechanical energy and electrical energy (hydroelectric). This potential needs depth studies to understand the interactions between turbines and marine currents with the water depth and velocity of tidal currents. The magnitude of a current in a specific location, it depends from the bottom of the sea and the coastline, for example, where there is a narrow cross-section increases the speed of the water flow. “Marine current turbines” use tidal currents to produce energy. A broad classification can be based on the difference between the oscillating and rotating devices. These devices maybe classified according to the direction of movement, considering both the vertical or horizontal turbines. Marine turbines with horizontal axis: the turbine blades rotate around a horizontal axis parallel to the direction of water flow; in marine turbines with vertical axis blades rotate around a vertical axis perpendicular to the direction of water flow. The horizontal turbines have been installed with tubular steel; the nacelle contains the mechanism for controlling the pitch angle of the blades and the generator. A submarine cable transports the energy produced. In recent years, the development of tidal power has led to the creation of several prototypes tested, in order to understand how these devices work and how to improve operating conditions and to determine precisely what level of maintenance are necessary to control performance. An example is the Sea Flow (Figure 21) installed on the north coast of Devon, England, in the summer of 2003. It is a marine turbine with horizontal axis, with a rotor of 12 m giving a nominal power of 300 kW with a current of 2.7 m/s, with a hydrodynamic conversion efficiency greater than 40%.

Figure 21: Sea Flow turbine

However, there is a big problem that affects the widespread exploitation of this technology: the lack of network connection points and the environmental impact that could have an effect on local wildlife. The horizontal turbine maybe considered as the "aquatic sister" of the wind turbine.

3. Composite materials in wind energy

The objective of scientists and engineers is to improve the properties of traditional materials, or to discover new materials. The "composite" are an example of the latter category; such materials have already been used for the production of more than 200 thousand wind turbines in the world, in particularly for large turbines. Due to the reduction of fossil fuel reserves in the world, a particular interest is to find an unlimited source of energy represented the main objective for scientists and engineers. These facts focus the attention to the development of alternative energy sources that are environmentally friendly and renewable. The exploitation of wind energy is a promising technology and wind turbines are a convenient way to capture and convert the kinetic energy from the atmosphere, in electricity. The term "windmill" applied to the first machine, but the modern ones more properly called "Wind Turbines". The wind turbines, due to changes in wind are subject to cyclic loading, turbulence, wind shear, and other effects, such as changes in air pressure, so it is necessary to ensure reliability and stability at every little blade deflection under wind loads. This is achieved, for some parts, using a sandwich composite, which ensure a higher rigidity to the composite, placed between two composite layers, are typically polymers foams, the blades are produced by long fiber reinforced polymer, which provide longitudinal rigidity and resistance, while the resin matrix is responsible for the toughness (resistance to delamination). The stiffness of the composite determined by the stiffness of the fibers and their volume fraction. Some composite blades designed and manufactured using the vacuum infusion. This building method allows the resin completely to saturate the glass fibers and allows an excellent ratio fiber/resin, since the vacuum minimizes the amount of air pits that formed between the fibers, and the permeability of the fibers glass. The components of the blades constructed using special molds and glued with structural acrylic adhesives, which offer as result a durable product and lightweight while also providing benefits in assembly time and protection against corrosion. The structural acrylic adhesives are very high shear strength, allow them to be strong in welding and maintain their strength in a wide temperature range 40 to 170 °C.

3.1 Brief history and main features of a wind energy system

The wind has played an important role in the history of human civilization. The first known use of wind was 5000 years ago in Egypt, in which they were used the sails of the boats. The technology to convert the kinetic energy of the wind into mechanical energy has been applied by man since ancient times. Some said that the use of wind power have its origin in the Asian civilizations of China, Tibet, India, Afghanistan, and Persia.

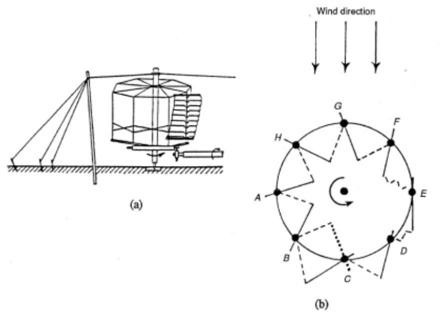

Figure 22: The vertical-axis Chinese windmill

The earliest written evidence for the use of wind turbines was the one of "*Erone di Alessandria*", exactly in the third or second century B.C. in which is described a simple horizontal axis wind turbine. In 7th century B.C., Persians have used the power of the wind by a machine with a vertical axis.

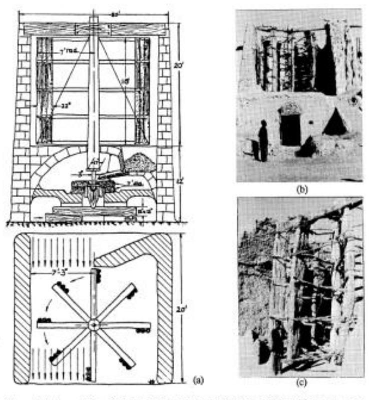

Figure 1-3. An existing windmill of the Persian type in Neh. (a) The millstones are now below the rotor and the sails are bundles of reeds [Wulff 1966]. (b) A general view of the downwind (south) wall of the mill. (c) Close-up view of the reed sails. (*Reprinted by permission of MIT Press; ©1966, MIT Press*)

Figure 23: The vertical-axis Persian windmill

With the introduction of the steam engine in the 18th century, the world has gradually changed its power demand. Especially with the introduction of fossil fuel (coal, oil and gas), the advantages of these machines have become more significant. Oil and gas turbines, are much more compact and can provide energy at a much larger scale. Therefore, the importance of wind energy as an energy source decreased during the 19th. With the industrialized world, the role of wind power has decreased. The first blades to produce electricity was realized in the early 1900s in Denmark, had a wind turbine with an average power of 20-35 kW for a total of 3 MW of total capacity which corresponded to the 3% of the electricity produced to the entire country.

According to the arrangement of the rotor respect to the wind direction, the wind systems classified into two broad categories:

- vertical axis;
- horizontal axis.

The first had a horizontal axis and used for mechanical work such as pumping water, grinding grain, sawing wood. They were built on platforms around which could rotate to follow the direction of the wind ("post mill").

Figure 24: Post mill

Modern wind turbines classified according to the energy produced which strongly influenced by the size of the rotor:

- small turbine : P <100 kW (rotor diameter: d <20 m);
- average size of turbine 100 kW <P <1000 kW (rotor diameter: 20 m <d <50 m);
- large turbine: P> 1000 kW (rotor diameter: d> 50 m).

3.2 General configuration of a wind turbine

The blades attached to a hub and together constitute the rotor; the hub connected to a main shaft, or *slow shaft*, which rotates at the same angular velocity of the rotor. The shaft connected to a *gearbox*, which branches with a *high-speed shaft*. On the latter is installed a *brake*. In most of machines, all the mentioned components are located in a cabin called *nacelle*, which positioned on a *yaw ring* adaptive according to the wind direction. The entire nacelle positioned on a tower that can be conical or tubular. In addition to these components, there is a *control system* that has, in the more general case, several functions: controlling the power that can be performed by controlling mechanically, electronically and hydraulically the rotation of the blades around their main axis (system of pitch adjustment, pitch regulation), and the lift. The control of the orientation of the nacelle known as *yaw control*, which is important to keep the machine oriented in the direction of the wind.

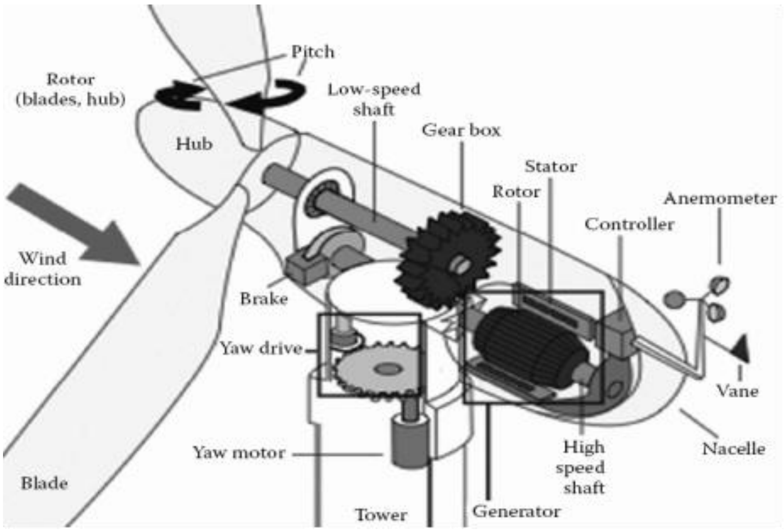

Figure 25: Wind turbine elements

Positive aspects of wind energy:

- does not occupy a very large area (about 3-5% of the area available);
- good impact statement because there is an increase of work;
- good conversion of wind power into electricity, with a theoretical yield of 60%;
- does not produce emissions;
- projects are simple and inexpensive;
- low maintenance cost;
- average life of a turbine of 20-25 years;

The wind system is present mainly on the islands as it turns out to be cheaper than the transmission of electricity from the mainland.

Negative aspects of wind energy

The *visual impact* of wind energy is the most significant barrier. Very often, the sites of interest are areas of significant environmental and landscape value. It is possible to minimize the visual effects "unpleasant" related to the presence of the turbines through constructive solutions.

The *noise* caused by electromechanical components and especially from aerodynamic phenomena that take place with the rotation of the blades and the dependent on their characteristics.

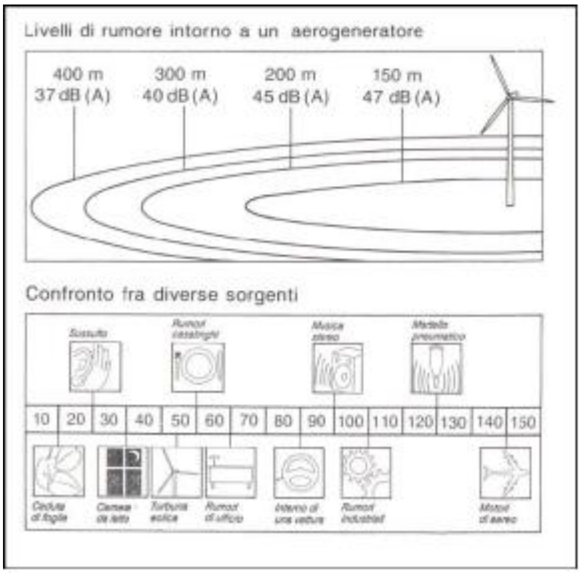

Figure 26: Noise level around a wind turbine

The generation of *electromagnetic interference* from the turbines, that may depend on:

- the characteristics of the blades;
- the characteristics of the signal receiver;
- the frequency of the signal;
- the type of radio wave propagation in the atmosphere.

Studies still in progress show how it is possible to avoid such interference (except for radar signals) using non-metallic materials for the construction of the turbines.

The potential *impacts on flora and fauna* are the main factors to be considered for the environmental changes. Regarding the flora, vegetation loss depends on the size of the area destined to the wind farm and to the geomorphological characteristics. In the case of the wind turbine, the greater problem related to the presence of birds.

The potential impacts are due to:

- Collisions;
- Electrocution;
- Noise disturbance;
- Loss or alteration of habitat.

3.3 Wind turbine systems

Systems connected to the distribution network

The wind farms are groups of more turbines interconnected. Economic and functional aspects dictate the use of this type of arrangement: economically the most advantageous solution, in fact, is to generate power with a large number of machines. The turbines also must be positioned on the territory at a safe distance from each other to avoid the aerodynamics interference phenomenon, which has two types of result: the first related to the increase of turbulence on the machines positioned within a wind farm, the second is the loss of power. The turbines can be placed both on land (onshore) and offshore.

Figure 27: Onshore system

Offshore installations

In the case of installation of these facilities, costs are higher, but the cost offset by an increase in production of 30%. The development of this mode plant requires a large number of large wind turbines in order to offset the high cost of installation, connection to the mainland and remote monitoring. Existing installations, mainly for economic reasons, are made in shallow water (<20 m) and not far from the coast.

Figure 28: Offshore system

4. Multi-functional prototype wind turbine

In the broad scenery of the new frontiers of technology, including in the renewable energy is increasingly claiming the use of innovative composite materials. It is preferred to speak of materials for structural applications (characterized by good mechanical properties) and of materials with specific functionality (piezoelectric properties, optical, photovoltaic, bio, etc.) that it can be used in applications with high benefit. These features, for example in the wind energy sector, can be obtained thanks to new production processes, a new fibre or treatments or, still, in particular structures of the tissues. In addition, recent advances, materials science information, led to the textile a new role, that makes it potentially available to the use of new technologies based on the integration of these disciplines. Thus, the development of textile products with multifunctional characteristics necessary to be defined intelligent appears today as one of the most interesting opportunities for the development of the textile industry. Fabrics for composites and other related applications are an area of particular importance because they combine mechanical performance able to withstand high loads without compromising weight. In this technological landscape, the thesis project focused mainly on the wind sector. In particular, the analysis of the feasibility of a wind turbine with innovative features. The purpose of the project attributed to wind turbine piezoelectric-photovoltaic characteristics. The design of the blade will be crucial, as it will depend on both the mechanical properties than those piezoelectric-photovoltaic. For this purpose, the choice has focused on the design proposed by the inventor on the innovative blade Renzo Piano. The design of the blade runs on the joint efforts of Renzo Piano and Enel Green Power with the name “Dragonfly ". Different from other wind turbines, characterized by only two blades, which are aligned with the central column, 20 meters high and very thin due to the structure mostly “empty “of the blades themselves. Compared to the traditional three-blade wind turbine, in this case installed a two-bladed turbine to reduce its visibility, but not neglecting its efficiency, also under conditions of no winds. In addition, the light and transparent structure, with steel parts, carbon fiber and polycarbonate allows the turbine to blend into the surrounding environment. The project aims at integrating the blade, designed by Renzo Piano, with piezoelectric characteristics and the characteristics of photovoltaic. The result of this innovative blend will be the prototype wind turbine multifunctional. Despite its limited size, which allows it to be well camouflaged in the landscape, the mini blade is proving to be the first test of being able to work even with winds of low intensity.

This is possible thanks to the super lightweight materials of which it composed and new technological solutions employed for its realization. (Renzo Piano Building Workshop, Eolic Windmill 2009-2011)

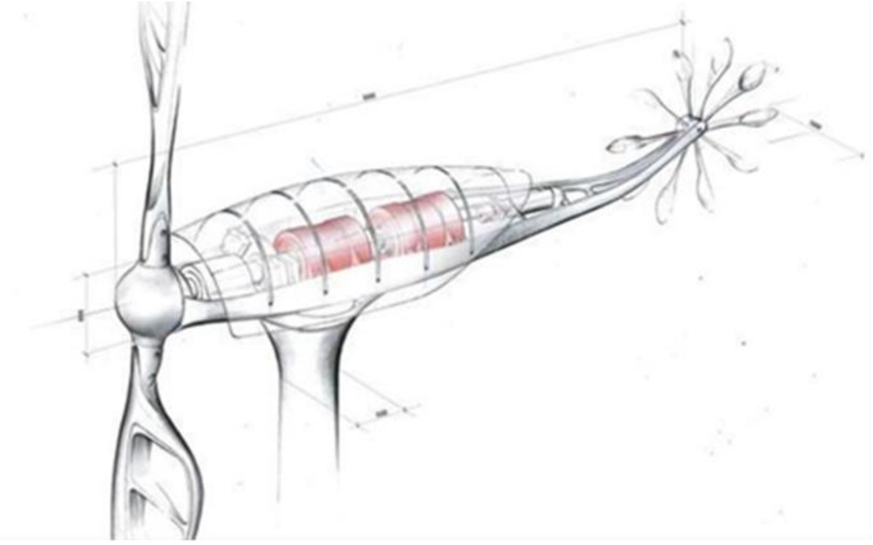

Figure 29: Wind blade of Renzo Piano

In the realization of wind turbines, are used both fibrous and other materials, polymeric and still traditional. In the case of the blade, the metallic materials have a more content if not even marginal and unexpected to a certain increase. The man-made fibers have, however, a greater growth potential, because you can give more and more features tailored to the needs of specific applications. Characterized primarily for their high levels of resistance to mechanical stresses, to fire and to chemical agents. All chemical fibers (man-made fibers) have a high technical content, but the attribute "technical" should be understood in reference to the application areas and manufacturing technologies. With this orientation, technical fibers are those used in the manufacture of structural parts when they require levels of performance and quality such that traditional materials cannot provide. The textile technologies, employed in the realization of the blade are substantially similar to those employed for the realization of the laminates. An innovative textile technology developed in Italy exploited by a research project called “tetraxial” at the “Politecnico di Milano”. The aim of my thesis project is to optimize and the use of new conception which has three weft yarns, two of which in the direction not perpendicular to the warp. In addition, it will test the feasibility of using, within the fabric, a fiber with photovoltaic-piezoelectric characteristics to increase the energy efficiency of a wind turbine.

4.1 Definition of the multifunctional prototype

Before you make the realization of the prototype will be necessary to define in detail the main features that are fundamental to the design and innovation of the prototype. Regardless of the type of product and/or needs, the steps that activated for the realization of a prototype are:

- Materials research according to specific needs;
- Structural analysis;
- Feasibility and economic considerations.

The construction of the wind turbine multifunctional sees its development, analysis and execution of the above-mentioned steps.

4.1.1 Materials used and main characteristics

Tetraxial fabric

Morphological characteristics: has been developed a weaving machine, which can produce a special weave which define tetraxial, formed by the warp yarns, weft yarns and traditional two yarns with different diagonal directions, with respect to the warp, normally at 45 °, but that can vary between 30 ° and 60 °.

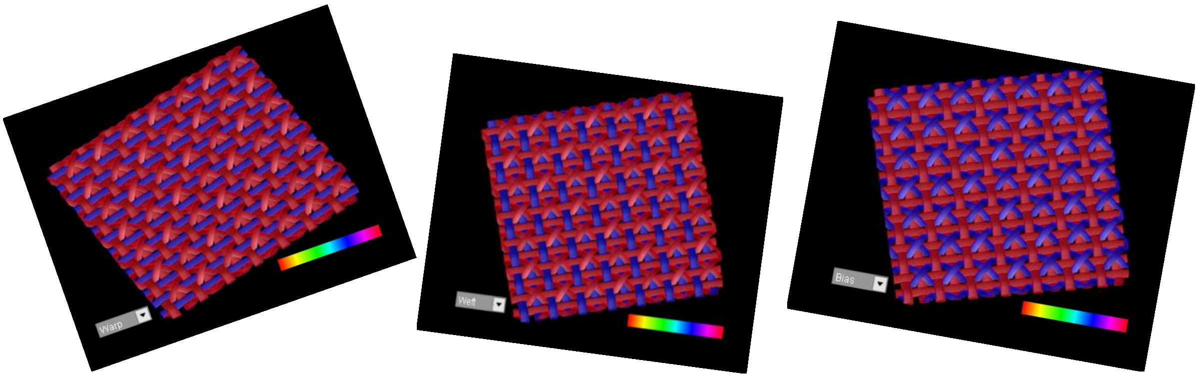

Figure 30: Representation of the weft yarns, the warp yarns and the two one in diagonal directions

Characteristics:

- Isotropy: dimensional stability in all directions;
- Filling: The filling factor can be changed from 100% to 30%;
- Weight: the fabric tetraxial with filling factor of 100% has a specific weight equal to a traditional fabric made with the same type of yarn;
- Conformability: it can easily be modelled on a non-planar surfaces;
- Appearance: the typical frame offers a new appearance;
- Tear and cut-resistant.

Advantages:

Current methods for obtaining isotropy exploit stickers or transverse seams to tie together layers of fabrics in different orientations. Instead, the fabric tetraxial achieves the same result in one-step giving multiple advantages:

- Minimum waste: no cutting corners in overlapping fabrics;
- No added materials: do not use glues or additives;
- Low cost: no specialized labour, less manipulations; less operations reduces the production costs;
- Weight: the specific weight is reduced as a result of the formation of a single layer;
- Manipulation: it can be manipulated as a common fabric.

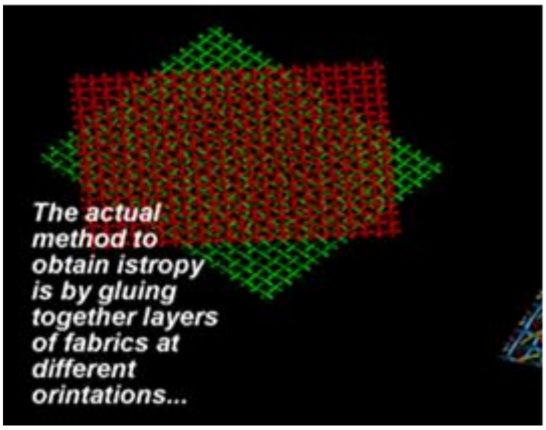

Figure 31: Overlapping fabrics

Results:

The frame newly built and ruled by patents, is the combination of two traditional weaving machines: a flat machine and a circular.

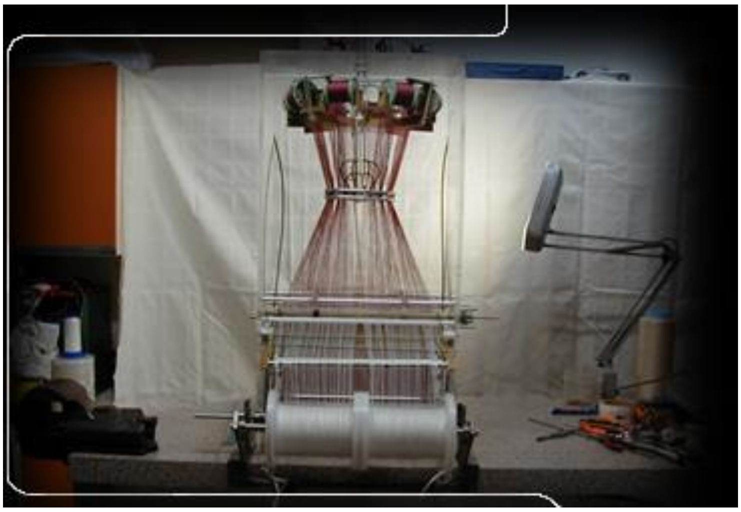

Figure 32: Weaving machine

- The machine used for the tetraxial fabric is a new design concept;
- Has been already produced a prototype weaving machine which has given excellent results;
- The machine derived from 60% of existing components.

Economic aspect:

The cost of the fabric can be placed just below the price range of a multiaxial fabric. The prototype machine operates automatically, requiring no specialized labour.

The main economic impact will depend on:

- Cost of materials chosen;
- Cost due to processing waste (less than 3%).

4.1.2 Materials used in interweaving

For the creation of the interweaving can be used in weft and warp the glass fiber, whereas for the two wires diagonals will evaluate the possibility of using a piezoelectric-photovoltaic fiber. The blend in this configuration, it will keep the mechanical characteristics (typical fiberglass) with the more innovative features of photovoltaic-piezoelectric fibers.

Piezoelectric-photovoltaic fiber

Renewable energy sources are endless, but is not available at all times. For example, the generation of electricity from a photovoltaic material depends on the density and the number of light photons absorbed by the photoactive layer. If the solar radiation is low in a region, for example, on a cloudy day, the generation of electric power will be less. If the flexible solar cells (in the form of fiber) are coupled with flexible piezoelectric materials, then we will have a hybrid structure that can generate energy from solar radiation and the mechanical energy, such as wind, rain, waves etc. Has been developed a new technology from *Prof. Siores*[4] that integrates a piezoelectric substrate and polymer coating system photovoltaic to create a film or a fiber structure capable of transforming both mechanical energy (using the piezoelectric part) and the energy of light (using the photovoltaic part). The resulting system is flexible and can be incorporated into a wide range of applications in different environments on earth, underwater and possibly space.

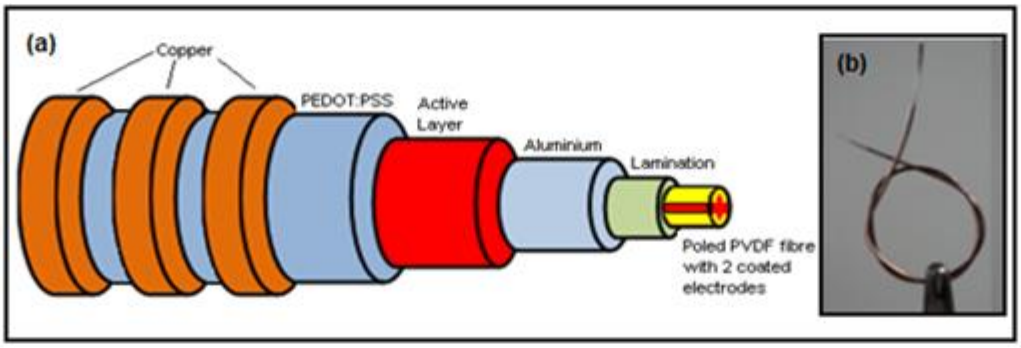

Figure 33: Piezoelectric-photovoltaic fiber

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[4] Prof. Elias Siores is the Provost of Bolton University and the Director of Research and innovation.

This technology is capable of producing electrical energy from the environment and provide energy production almost continuously. The flexible structure can be part of any material such as sailing, window curtain, and curtain and generate renewable energy even in the absence of sun. This structure can replace the conventional photovoltaic power that require large panels and tracking devices of the sun. Because the hybrid structures produce energy by combining the piezoelectric technology, which converts mechanical energy into electrical energy fluctuating (AC) and photovoltaic that converts solar energy into electricity (DC), a rectifier circuit associated with four diodes and a capacitor can be used to rectify the voltage fluctuating at various frequencies in a DC voltage constant. The constant voltage generated can be stored in an electrical storage device such as batteries and super capacitors or can be used directly in line. (Prof. Elias Siores; Smart materials in renewable energy applications)

Piezoelectric characteristics and photovoltaic one

The piezoelectric effect exists in two modes, namely, direct piezoelectric effect and inverse piezoelectric effect. The direct describes the ability to convert mechanical energy into electrical energy (also known as generator or transducer), while the inverse piezoelectric effect describes the ability to transform electrical energy into mechanical energy (also known as an actuator). The electrical energy obtained by the direct piezoelectric effect can be stored to power electronic devices and known as "energy/power collection." Piezoelectric materials are type of ferroelectrics, where the molecular structure is oriented in such a way that the material exhibits a local charge separation, known as electric dipole. The electric dipoles in the piezoelectric materials are randomly oriented, so that the material does not have the piezoelectric effect. However, the electric dipoles themselves are able to redirect their position when a strong electric field applied as shown in Figure 34.

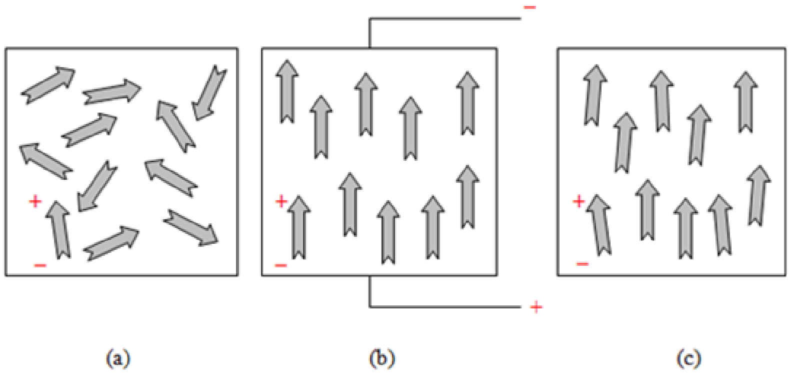

Figure 34: Orientation of the poles through polarization

We speak of "direct piezoelectric effect", when a mechanical stress is applied to the crystals, an electric charge is generated on the surface of the crystal and the polarity of the electric charge observed on the surface can be reversed by reversing the direction of the applied mechanical stress, as shown in Figure 35.

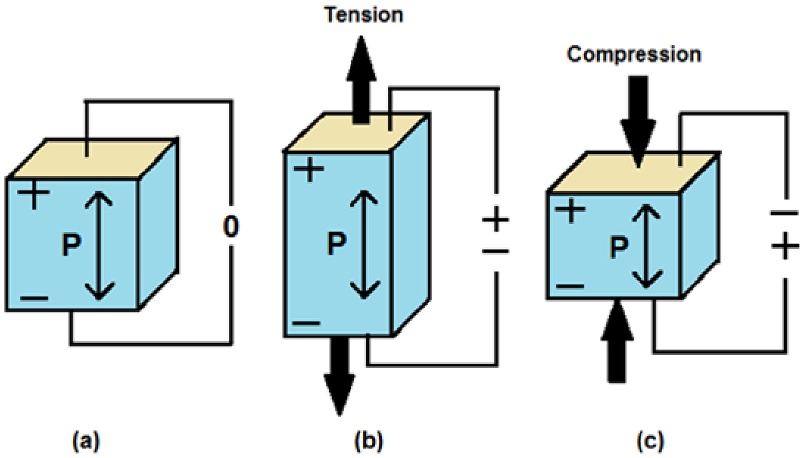

Figure 35: direct piezoelectric effect

While, it is an "inverse piezoelectric effect", when an electric field applied to a crystal or a crystal subjected to an electric field, a mechanical deformation on the surface observed which generally regarded as a change in the size of the crystal. The direction of the mechanical stress can also be reversed, as shown in Figure 36, by reversing the applied electric field.

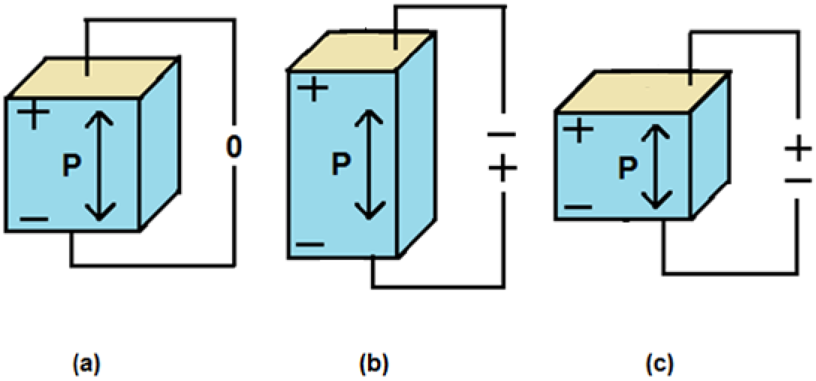

Figure 36: Inverse piezoelectric effect

The piezoelectric substrate made from a polymer. Preferably, (PVDF) or polypropylene or nylon. The piezoelectric substrate can include dispersed piezoelectric ceramic particles. The performance of the piezoelectric fiber were analyzed by measuring the characteristics of a PVDF polymer under the action of the wind. The analysis was carried out using the "Wind Tunnel Experiment", whereas two different conditions (with the single piezoelectric fiber with the piezoelectric-photovoltaic fiber). The results obtained are comparable and are not very different from each other. (Prof. Elias Siores; Smart materials in renewable energy applications)

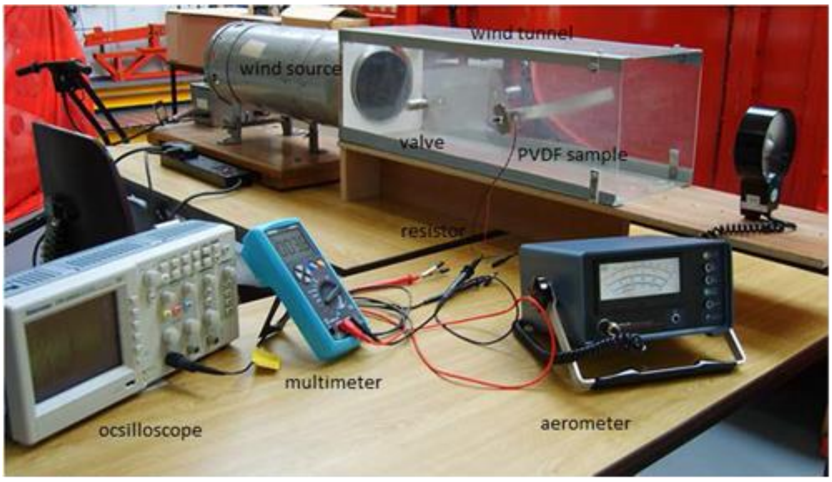

Figure 37: Wind Tunnel Experiment

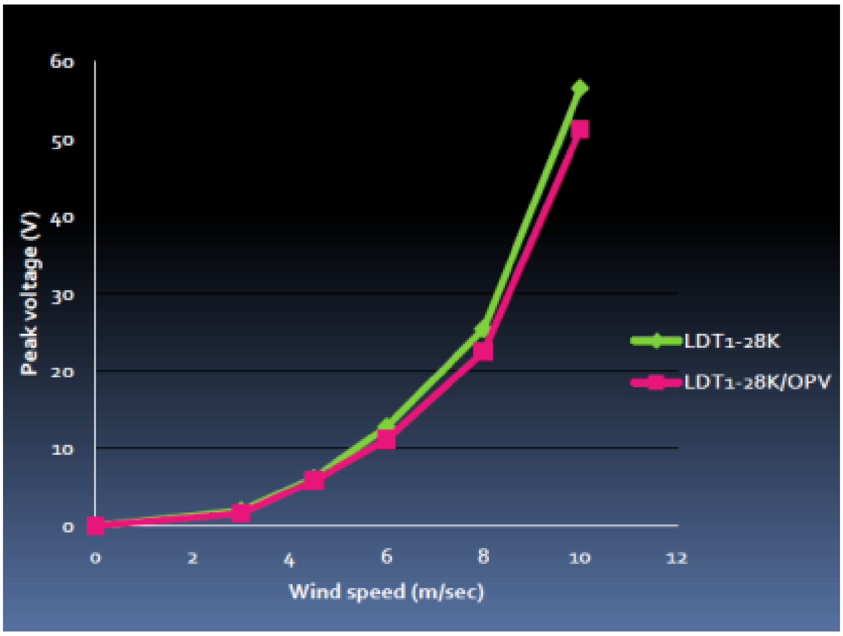

Figure 38: Results of the experiment

The photovoltaic effect can be described by understanding the functioning of the common organic photovoltaic (OPV). The choice to use such a system derives from the nature of the materials used. In fact, the polymers semiconductors with band gaps suitable have absorption characteristics and physical properties that can be used for the manufacture of organic photovoltaic materials. They are cheaper compared to inorganic solar cells based on silicon and may be fabricated using cheaper processing techniques. The photovoltaic effect based on the transfer of electrons from a donor to an acceptor. These materials have the donor-acceptor heterojunction to achieve the separation of electron-hole pairs.

There are six basic operating principles for a polymer solar cell:

1. Pair of photons;
2. Atoms on the active layer;
3. Creation of electron-hole pair;
4. Charge separation;
5. Load transport;
6. Collection of charges.

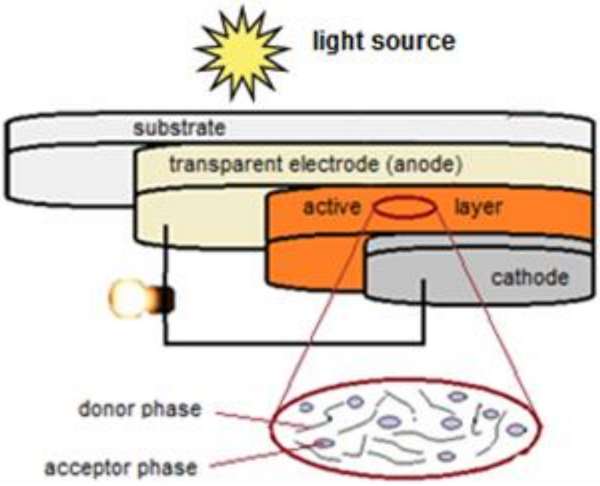

Figure 39: Typical organic solar cell

Below a list of possible electron polymers:

- poly(3-hexylthiophene), (P3HT);
- po5ly(3-octylthiophene), (P3OT);
- polyphenylenevinylene, (PPV);
- polyfluorene, (PFO,);
- poly[2-methoxy-5-(3,7-dimethyloxy)]-1,4-phenylenevinylene), (MDMO-PPV);
- poly[N-9’-hepta-decanyl-2,7-carbazole-alt-5,5-(4’,7’-di-thienyl-2’,1’,3’-benzothiadiazole, (PCDTBT).

The photovoltaic part constituted by nano-layers of polymer-based organic compounds. A flexible solar cell, comprised of a polymer based anode and a cathode to collect electrons. The photovoltaic performance of the fiber were analyzed by measuring the current characteristics under conditions of type AM1.5 (air mass coefficient). The analysis was carried out considering two different photoactive layer (MDMO-PPV: PCBM and P3HT: PCBM). For the fiber layer with photoactive P3HT: was obtained a maximum power (Pmax) of about 0.11 W, whereas, the layer of type MDMO-PPV: the maximum power obtained was approximately 0.21 W. The maximum power has been obtained in the case with type active layer of MDMO-PPV, resulting in a higher conversion efficiency.

4.1.3 Materials used for the composite

The technology used in wind turbine blades has evolved over the past 20 years. The first blade construction techniques have grown thanks to the construction techniques in the marine industry. The vacuum infusion, for example, brings the technology of manufacturing of the blade to a higher level, with improvements in the consistency and performance of a blade. Instead, the materials used in the production of the blade does not have evolved so rapidly. The resin, for example, has remained the same but with the advantage of be produced on a large scale. Wood or foam still used in many cases. The lamination layers made up of multi-axial fabrics or unidirectional one, even if the ultimate goal is to ensure isotropic characteristics. The performance of a wind turbine mainly based on the type of material used to make it. The literature offers cases in which the maximum performance obtained, related to lamination techniques of infusion. These materials used on the latest generation of wind turbines. The properties of the composite, in the case of infusion, particularly depend on the resin used, the volume fraction of the fabric and the complexity of the material. In fact, the transition from a unidirectional fabric to biaxial or triaxial, radically changes the characteristics of the final composite. The type of fiber and the amount of fiber determines the performance of the composite material as dictated by the "rule of mixtures". The advantage of a high performance fiber such as carbon is more prevalent in tensile properties. In the design of a blade, the advantage of the new fibers such as carbon made in the direction of traction. In contrast, compression properties for carbon fiber reinforced laminates do not differ appreciably from convenient alternatives such as composites based on glass fiber. The higher performance laminates show benefits in uniaxial but not in biaxial one. Since these fabrics are more complex, there is also a greater probability for defects that may compromise the properties of the laminate. As we move further innovation of the structural fabric, the performance data, due to the complexity of the fabric, tend to decrease the loss of alignment of the fibers, pressure loss and the reduction of the effective volume fraction. The option may be to change the properties of the materials to increase the flexural stiffness of the composite. For example, we can make a more rigid structure, increasing the volume fraction of the fibers within the composite. Another approach is to change the composition of the fibers to provide a stiffer fiber. It is also important to provide materials with low probability of defects, which ensures a smaller number of defects that can become sites of crack initiation in the case of large stresses.

The fundamental elements in the realization of the composite are the *matrix* and the *reinforcement*. The matrix constituted by a homogeneous continuous phase, which has the task of:

- Enclose the reinforcement, ensuring the cohesion of the composite material (and for any layers of which it is composed, in the case of composite laminate);
- Ensure that the reinforcing fibers has a homogeneous dispersion in the composite.

In the case of multifunctional wind blade will be used a transparent amorphous resin (typically an epoxy), to ensure a degree of light transmission more similar to the glass. In the wind turbine multifunctional, permeability to light is one of the important features and made possible thanks to the use of an amorphous resin. Clear, colorless with low tendency to yellowing, suitable for cold stratification with fiberglass, carbon and Kevlar. You get laminate with excellent mechanical strength, stiffness and impact resistance. Product is very versatile and easy to use; impregnation facilitated with low viscosity and good wetting of the fibers. The hardening can be accelerated with the aid of heat; also, a post baking at 40 ° significantly improves the characteristics of the laminate.

Figure 40: Transparent amorphous resin

The reinforcement has the task of ensuring rigidity and mechanical strength, taking upon itself the most part of the external load. In the case of multifunctional wind blade will be used a reinforcement type tetraxial (formed by the warp yarns, weft yarns and traditional two yarns with different diagonal directions, with respect to the warp, normally at 45 °, but which can vary between 30 ° and 60 °). In particular, the fabric tetraxial composite will be inserted in the empty sections of the blade. The blend of fiberglass and photovoltaic-piezoelectric one will ensure resistance to wind and not neglecting the piezoelectric-photovoltaic characteristic.

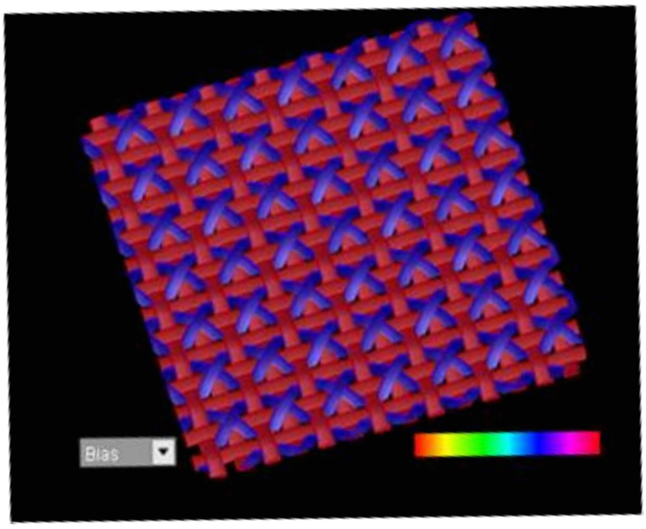

Figure 41: Tetraxial fabric

We have spoken of the composite and the materials used for the realization, but we have referred only to the materials that define the structural characteristics of the blade. In the case of multi-functional wind turbine is right to do considerations, also the characteristics of photovoltaic aspect. In fact, the blade as well as having a potential energy of wind type, also has a photovoltaic potential energy. To improve these characteristics, the composite laminate must be inserted in the empty space sections of the blade. The section will be the one that will be well positioned upwind of the wind turbine, as shown in Figure 42. In this way, when a beam of light (optical radiation) strikes the surface two different phenomena can be observed:

1. absorption, which can partly be transformed into electrical energy thanks to photovoltaic-piezoelectric fiber;
2. transmission across the material.

Figure 42: Upwind side of the blade

In the second case, the solar radiation, once it has passed through the material, it will possibly be subjected to a second absorption. In fact, adding another composite laminate, in a position opposite to the first, it will be possible to collect the radiation that is not absorbed in the first laminate. In this way, the light absorbed by the piezoelectric-photovoltaic fiber, will be greater than the single incident light absorbed condition (position upwind of the blade, Figure 42).

The piezoelectric characteristics, compared to those photovoltaic, will depend on the position relative to the neutral axis of the wind turbine blade. For neutral axis is defined as the locus of the points of a generic section in which the normal stresses are zero. It is that axis around which the section:

- In the case of bending moment, the neutral axis lies in the section and passes through the center of gravity;
- In the case of torque, the neutral axis is perpendicular to the section.

The piezoelectric effect will be greater in areas distant from the neutral axis of the blade, because there will be large amount of stresses, while in the other will be less.

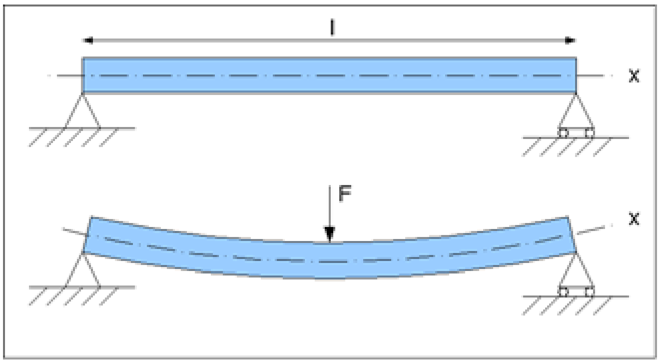

Figure 43: Neutral axis in direction x

4.1.4 Structural analysis

In the design of a structure, for example a wind turbine, the calculation of deformation of the body due to the applied loads, is a fundamental requirement. The behavior of the structure depends on both the geometry and both on the type of constraints, but mainly from the nature and properties of the materials used. In the case under consideration, the wind turbine has already been developed, tested and implemented, and then the structural analysis will focus only on the tetraxial composite laminate. In designing a composite laminate and need to know the relationships between the type of lamina and packaging sequence, between the mechanical characteristics of the lamina and those of the laminate obtained. The structural composite laminates are obtained, generally, by the superimposition of layers of thin continuous fiber, unidirectional or woven, impregnated with resin (lamina) and arranged in configurations desired, until the result of the desired characteristics. This called "lamination".

The study of composite materials can be undertaken through two approaches: micromechanical or macro mechanical:

- Micromechanics: study of the behavior of the composite material through the interactions of its components (matrix and reinforcement). Allows to derive the average properties of the material and assess how to proportion and have fibers and matrices to obtain particular mechanical characteristics;
- Macro mechanics: study of the behavior of the composite material considering only the mechanical properties of the material apparent global supposed homogeneous (non-isotropic).

In the case of a wind turbine, will be considered the first approach: the micromechanics (or, more precisely, micromechanics of materials) is the analysis of composite materials or heterogeneous at the level of individual components that constitute these materials. Heterogeneous materials, such as composites, solid foams, consist clearly distinguishable constituents (or phases) that show different material properties. Given the properties of the material (linear and/or non-linear) of the constituents, an important objective of micromechanics consists in predicting the response of heterogeneous material based on the geometry and properties of the individual phases, task known as homogenization. The advantage of this approach is that the behavior of a heterogeneous material can be determined without resort to evidence. (Proprietà meccaniche e applicazioni strutturali dei compositi e dei tessuti; Carlo Poggi)

Most of the methods of micromechanics of materials based on the continuum mechanics, rather than on an atomistic approach. The mechanical responses of inhomogeneous materials can be studied with analytical and numerical methods continues. One of these models known with the name of the founder, the Chamis's model (1984), which allows deriving the actual properties of the composite layers. (Structural Engineering Software for the Analysis of Space Frame Structure Composed of Fiber Reinforced Composite Materials; Gwang-seok Na)

The mathematical result stated by the Chamis's model is the following:

$E_{11} = E_f \mathrm{v_f} + E_m \mathrm{v_m}$	Effective longitudinal Modulus
$E_{22} = E_{33} = \dfrac{E_m}{1-\sqrt{\mathrm{v_f}}\left(1-\dfrac{E_m}{E_f}\right)}$	Effective Transverse Moduli in axes 2, 3
$G_{12} = G_{13} = G_{23} = \dfrac{G_m}{1-\sqrt{\mathrm{v_f}}\left(1-\dfrac{G_m}{G_f}\right)}$	Effective Shear Moduli in plane 1-2, 1-3, 2-3
$\nu_{12} = \nu_{13} = \nu_f \mathrm{v_f} + \nu_m \mathrm{v_m}$	Effective Poisson's ratio in plane 1-2, 1-3
$\nu_{23} = \dfrac{E_{22}}{2G_{23}} - 1$	Effective Poisson's ratio in plane 2-3

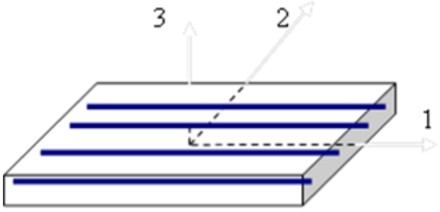

Figure 44: Directions in the plane

Where, “vf” is the volume fraction of the fiber, while “vm” is the volume fraction of the matrix. The resolution of mathematics Chamis allows us to determine the elastic properties of the matrix (Em, Gm, νm) and the elastic properties of the fiber (Ef, Gf, νf). These properties can be treated as average properties and average response of the composite system. Then, from the properties of the constituents, define a sort of composite "equivalent" to the real composite that is no more considered a heterogeneous material (operation of “homogenization”). In designing a composite laminate and is fundamental to know the relationships between the type of lamina and packaging sequence, between the mechanical characteristics of the laminates and those of the laminate obtained. The structural composite laminates obtained, generally, by the superimposition of layers of thin continuous fiber, unidirectional or woven, impregnated with resin (lamina) and arranged in configurations desired, until the result of the desired characteristics. This called "lamination". The sequence and orientation of the various lamina (defined lamination) established in the design phase of the component and characterized by a code of lamination (laminate orientation code). Assigned a reference axis on the laminate (x-axis), each lamina is identified with a number that represents the angle between the direction of the fibers and the x-axis (in the case of fabrics, reference is made to the warp direction). The orientation of the lamina is listed in sequence starting from the first lamina deposited, separated by a bar if the angles are different. To set the beginning and end of the code square brackets are used.

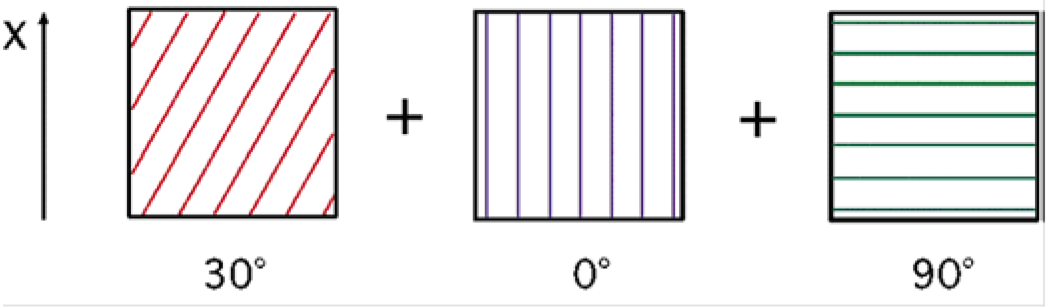

Figure 45: Example of lamination sequence [30/0/90]

The trend of deformation and stress in a composite laminate can be easily obtained under very simplified assumptions such as:

- The lamina forming the laminate are perfectly bonded so that no relative sliding can occur under the action of applied loads (continuity of displacements and deformations of the interface between two adjacent plates);
- The interface between the lamina is of infinitesimal thickness;
- Each state of the laminate is homogeneous, orthotropic or isotropic, of small thickness (plane stress state);
- The thickness of the lamina is small (plane stress state);
- The deformation in the z direction is negligible compared to the other directions.

The main objective, in the identification of the mechanical characteristics, will be to determine the stiffness matrix, of the laminate reinforced with isotropic fiber, and analyses how varies compared to the stiffness value of layer of polycarbonate. In this case, it was possible to find values thanks to the data reported in the literature. Generally, it is possible to find values around 2.3 GPa (under condition dictated by the standard DIN 53457).

In the case under consideration, take into account the following cases:

- The one with quasi-isotropic behavior: [0/45/-45/90];
- The one with isotropic behavior: layer of polycarbonate.

Once determined the actual properties of the composite layers, through the mathematical formulation of Chamis, and assuming that all the layers have the same thickness; it will be possible to determine the main stiffness matrix for our composite laminate. With the properties of the materials obtained, it is possible to determine the main stiffness matrices. Once it obtained the stiffness matrix calculated for each layer, it is possible to derive the relations resulting deformation, as seen in the classical theory of lamination, according to this form:

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ & A_{22} & A_{26} \\ sym. & & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{Bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ & B_{22} & B_{26} \\ sym. & & B_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ 2\kappa_{xy} \end{Bmatrix}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ & B_{22} & B_{26} \\ sym. & & B_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ & D_{22} & D_{26} \\ sym. & & D_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ 2\kappa_{xy} \end{Bmatrix}$$

Combining the above equations:

$$\begin{Bmatrix} \mathbf{N} \\ \mathbf{M} \end{Bmatrix} = \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{B} & \mathbf{D} \end{bmatrix} \begin{Bmatrix} \boldsymbol{\varepsilon}^0 \\ \boldsymbol{\kappa} \end{Bmatrix}$$

where A known as the extensional stiffness, B called the stiffness of coupling, and D called the flexural rigidity of the laminate.

It is important to notice that N are the menbranal stress matrix and M are flexural stress matrix:

$$\{N\} = \int_{-H}^{H} \sigma' \, dZ$$

$$\{M\} = \int_{-H}^{H} \sigma' \, ZdZ$$

The components of these three stiffness matrices defined as follows:

$$A_{ij} = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k \left(z_k - z_{k-1}\right) = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k t_k$$

$$B_{ij} = \frac{1}{2} \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k \left(z_k^2 - z_{k-1}^2\right) = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k t_k \bar{z}_k$$

$$D_{ij} = \frac{1}{3} \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k \left(z_k^3 - z_{k-1}^3\right) = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k \left(t_k \bar{z}_k^2 + \frac{t_k^3}{12}\right)$$

where t_k is the thickness of the k layers. The determination of these three stiffness matrices A, B, and D, is probably the most important step in the analysis of composite laminate. With the properties of the materials obtained, previously, it was possible to determine the extensional stiffness matrix:

Quasi-Isotropic case: [0/45/-45/90]

$$[\boldsymbol{A}] = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k \left(z_k - z_{k-1}\right) = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k t_k$$

$$= \begin{bmatrix} 43.36 & 9.310 & 0 \\ 9.310 & 43.36 & 0 \\ 0 & 0 & 17.03 \end{bmatrix} \quad \text{GPa-mm}$$

Volume fraction 20% and unit thickness

$$[\boldsymbol{A}] = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k \left(z_k - z_{k-1}\right) = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k t_k$$

$$= \begin{bmatrix} 58.79 & 13.76 & 0 \\ 13.76 & 58.79 & 0 \\ 0 & 0 & 22.52 \end{bmatrix} \quad \text{GPa-mm}$$

Volume fraction 30% and unit thickness

$$[\boldsymbol{A}] = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k \left(z_k - z_{k-1}\right) = \sum_{k=1}^{N} \left(\overline{C}_{ij}\right)_k t_k$$

$$= \begin{bmatrix} 75.14 & 18.33 & 0 \\ 18.33 & 75.14 & 0 \\ 0 & 0 & 28.40 \end{bmatrix} \quad \text{GPa-mm}$$

Volume fraction 40% and unit thickness

where [$\overline{\mathbf{C}}$]$_k$ is the stiffness of the k^{th} layer and t_k is the thickness of the k^{th} layer.

Now, consider only the menbranal stress matrix:

$$\{N\} = \int_{-H}^{H} \{\sigma'\}\, dZ$$

with

$$\{\sigma'\}^k = [C']^k \{\varepsilon'\}^k$$

where C' is the transformed reduced stiffness matrix of layer k.

In particular, it analyzed the case in which the menbranal stress are in x direction:

$$N_x = \int_{-H}^{H} \sigma_x \, dZ$$

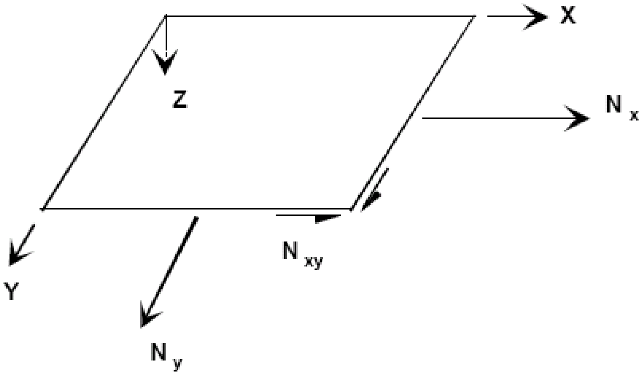

Figure 46: Menbranal stress

If it is considered the case in which my composite is subjected to traction (along the x axis), leaving it free to move along the other directions, and solving the menbranal stress matrix under these conditions, the behavior of my composite will be described by the following equation:

$$\mathrm{N_x} = \frac{\left[\mathrm{A_{11}} \ - \frac{(\mathrm{A_{12}})^2}{\mathrm{A_{22}}}\right]}{\mathrm{H}} \, \varepsilon_\mathrm{x} = \ \mathrm{E_x} \, \varepsilon_\mathrm{x}$$

where A is the “apparent stiffness” and $\mathrm{E_x}$ is the “apparent elastic modulus” in axial direction x, in a simple tensile test with free lateral expansion.

The work done allows deepening the knowledge of the behavior of composite laminate under different conditions. In particular, it has been possible to identify different properties between the laminate "quasi-isotropic" and the "isotropic" layer, comparing the values of the elastic modulus. The numerical simulations have allowed reproducing the behavior of laminate with low values of the volume fraction, until it gets acceptable values of elastic modulus depending on the amount of volume fraction. In particular, it was possible to determine the extensional stiffness matrix to describe a gradual increase of the stiffness, from which it was able to get the “apparent stiffness” simply dividing the stiffness by the thickness of the laminate. The “apparent stiffness” corresponds exactly to the “apparent elastic modulus” of the laminate: it is the relationship between the stress and the axial strain in a uniaxial tensile test, performed in the x_1 direction.

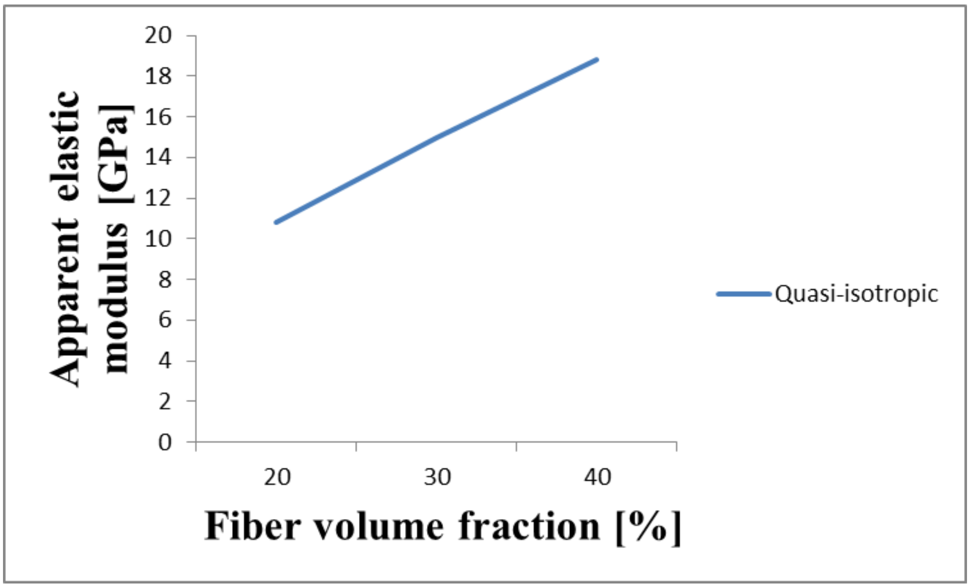

Figure 47: Apparent elastic modulus vs. fiber volume fraction of quasi-isotropic laminate

From the data reported above (Figure 47), it is evident that the “apparent elastic modulus” of the quasi-isotropic laminate, whose values change from 10 GPa to 19 GPa, is far from the value of the elastic modulus of the isotropic layer (only 2.3 GPa). This result suggests that the quasi-isotropic laminate has good mechanical properties, which are necessary for the structural requirements of the project. In fact, the reported results allow assuming the possibility to include the laminate in the empty sections of the wind turbine. This implementation will let to generate both piezoelectric effect (due to deformation undergone by the blades) and both by the photovoltaic effect (due to sun exposure), without affecting the structural efficiency.

To be sure, of these results, it is possible to make finite elements analysis by Abaqus 6.11.2. This program investigates the behavior of the polycarbonate layer and the quasi-isotropic laminate, under uniformly applied load. This load is due to the action of the wind that blows with an average speed of 7.5 m/s in the z direction. For the two cases, it will be considered the same geometry, a plate (100 mm x 100 mm) in which the thickness is equal to 4mm, but different values of the elastic modulus.

Isotropic layer of polycarbonate:

Elastic modulus (E) = 2.3 GPa

Uniformly applied load (q) = $\boldsymbol{\frac{\rho v^2}{2}}$ **= 35 Pa**

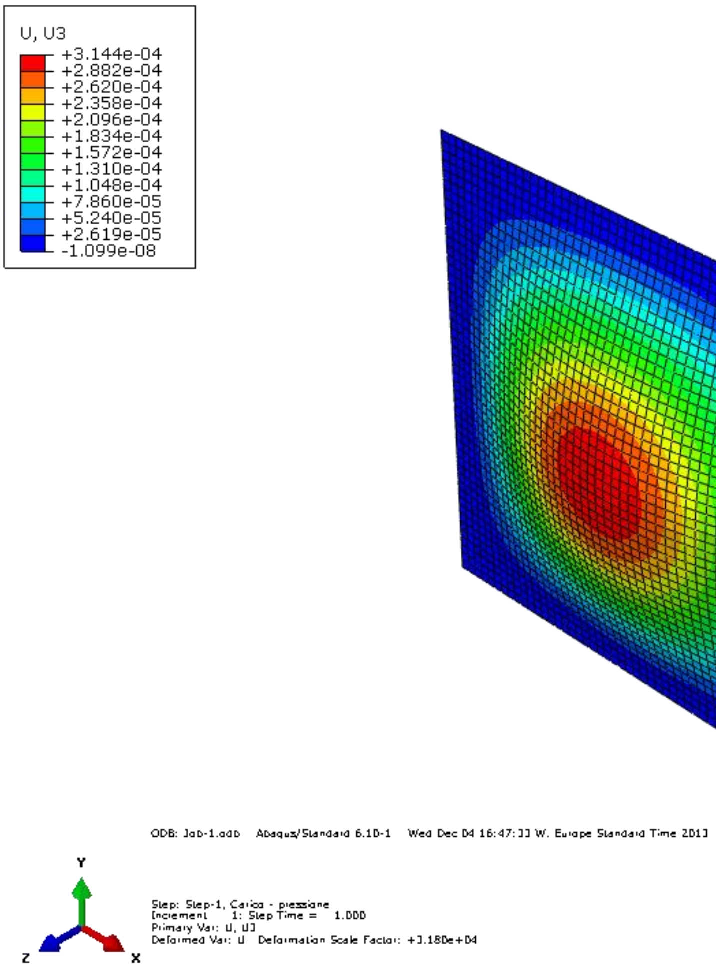

Figure 48: Displacement in isotropic layer

where, the maximum displacement value is 0,0003 mm.

Quasi-isotropic laminate with volume fraction of 20%:

Elastic modulus (E) = 11 GPa

Uniformly applied load (q) = $\frac{\rho v^2}{2}$ = 35 Pa

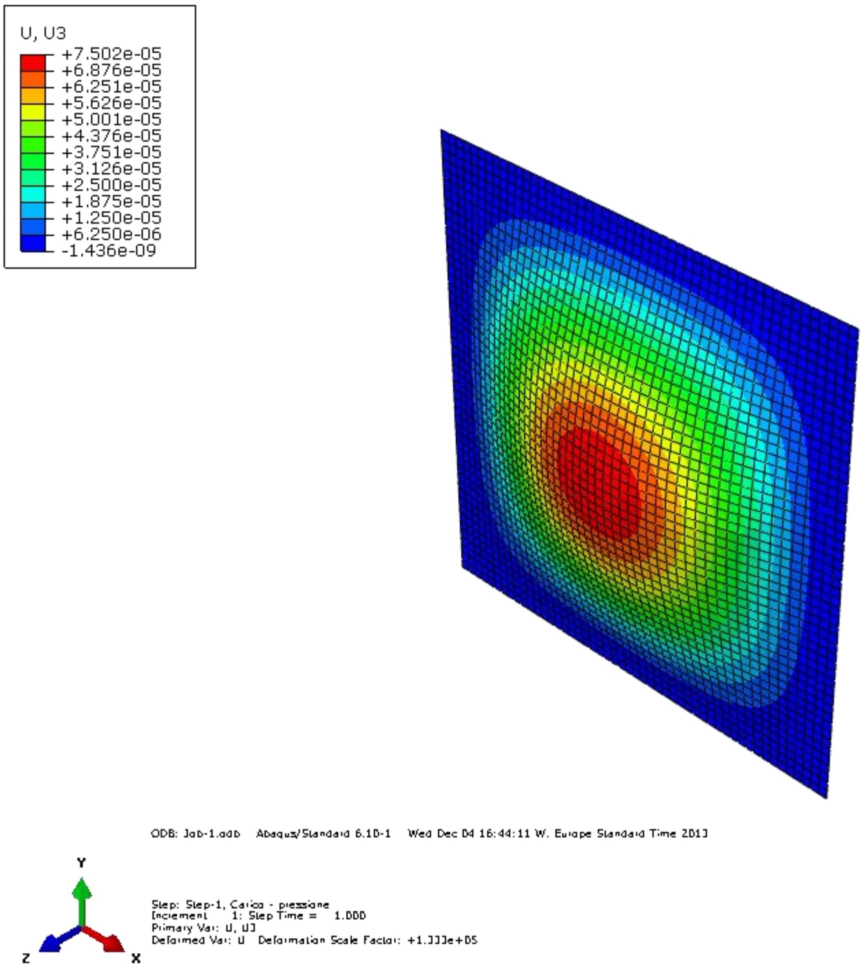

Figure 49: Displacement in quasi-isotropic laminate

where, the maximum displacement value is 0,00007 mm.

Comparing the data, it is evident that the displacement of the quasi-isotropic laminate is far from the value of the displacement of the isotropic layer. This result suggests that the quasi-isotropic laminate has good mechanical properties, which implies that its deformation is lower than the isotropic layer. In order to reach the same result of the quasi-isotropic layer it is necessary a value of thickness around 8 mm and this causes an increase in weight. In fact, the reported results allow assuming the possibility to include the laminate in the empty sections of the wind turbine.

4.1.5 Feasibility and economic considerations

In order to evaluate a wind power plant, the anemological investigation could be more expensive than the plant itself. The data of meteorological stations near to the site or wind maps (for example, the “Atlante Eolico Italiano”) can be used to support analysis. These instruments may be indicative but not sufficient to determine the conditions for the installation of a wind farm. However, it is preferable to carry out the anemological investigations to avoid investments in areas that might not be suitable. There are some general rules to follow to optimize the production of energy and avoid losses due to interference of obstacles (buildings, trees, etc.):

- with the exception of the smaller sizes turbines, towers of support should be a minimum of 10 meters high, preferably 18-20 meters;
- in the case of positioning upwind of the obstacle, the turbines should be at a distance equal to at least twice the height of the obstacle;
- in the case of positioning downwind of the obstacle, the turbines should be at a distance equal to at least ten times the height of the obstacle and, at a distance of fifteen times the height of the obstacle, the losses are negligible.

The generality of the last two rules depends strongly on the shape and arrangement with respect to the direction of the prevailing wind. In addition, it would be preferable to avoid the installation of wind turbines on buildings because they could create vibrations or turbulence. Further studies need to be done to assess the feasibility of a wind turbine affect to the winds. The wind is the result of the expansion and of the convective motion of the air caused by the uneven heating of the sun on large areas of the earth surface. The movement of hot air masses and cold one produces the typical areas of high and low pressure, so the air moves from areas of high pressure, where it accumulates more, toward those of low pressure, where it is less concentrated. The motion that results is the wind. When the difference between the two zones is high (high and low), and when they are very close, the wind speed will be greater. Effects of the morphology of the ground and of a natural relief or artificial can induce a reduction of the air mass producing and so an acceleration of the flow.

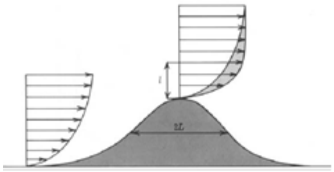

Figure 50: Effects of morphology

The presence of obstacles modify the field of motion of the wind by increasing the turbulence of the airflow. Therefore, in the design phase of a wind farm must be carefully evaluated the heights of the turbines and the relative distances between them. In assessing the energy potential of a site, the profile of wind speed at different altitudes parameterized by two laws: the law of power and the Prandtl logarithmic law. Both laws are simplified expressions of the real profile. They are valid only in the case of flat ground without obstacles. They can give information only for the portion of the boundary layer near the surface (approximately 50-100 meters) and implicitly assume that:

- the wind direction does not change with altitude;
- the rotational effects of the earth are negligible;
- the structure of the boundary layer is affected only by the friction with the surface and the thermal gradient.

The assessment of wind energy potential of a site anticipated by the evaluation of the characteristics of the selected site and the survey on the potential energy based on wind data collected.

The **characterization of a site** divided into the following phases:

- inspections of the preliminary assessment;
- installation of one or more anemometer stations, depending on the extension of the site;
- data acquisition;
- data processing;
- assessment of the potential energy (*micro siting*).

Preliminary **evaluations of the site** to define its "wind vocation" according to a series of parameters such as:

- presence of wind data;
- slope;
- coverage of tall trees;
- transport infrastructure;
- power lines;
- presence of urban or isolated houses.

The wind speed profile characterization of a site must go through the following activities:

- use data from neighboring meteorological stations;
- installation of one or more anemometer stations;
- periodic processing of the data collected;
- duration of at least one year of activities.

The study of the distribution winds is evaluated using winds maps (for example, the “Atlante Eolico Italiano”), these values being based on numerical modelling, and the correct assessment of the wind conditions of a site cannot be separated from the installation of sensors for detecting the characteristics of the wind. The data obtained from the following measurements used to perform analysis. The anemometer station is equipped with detection kit of the wind (speed sensors or anemometers and wind direction sensors) positioned at different heights, data logger (with optional GSM data transmission), battery or solar panel for power equipment. The choice of the height and position of a anemometer station can be made on the basis of already existing data. As mentioned you can use existing data provided by instruments present on the Web (Atlante Eolico Italiano) or institution for research (Istituto Superiore per la Protezione e la Ricerca Ambientale).

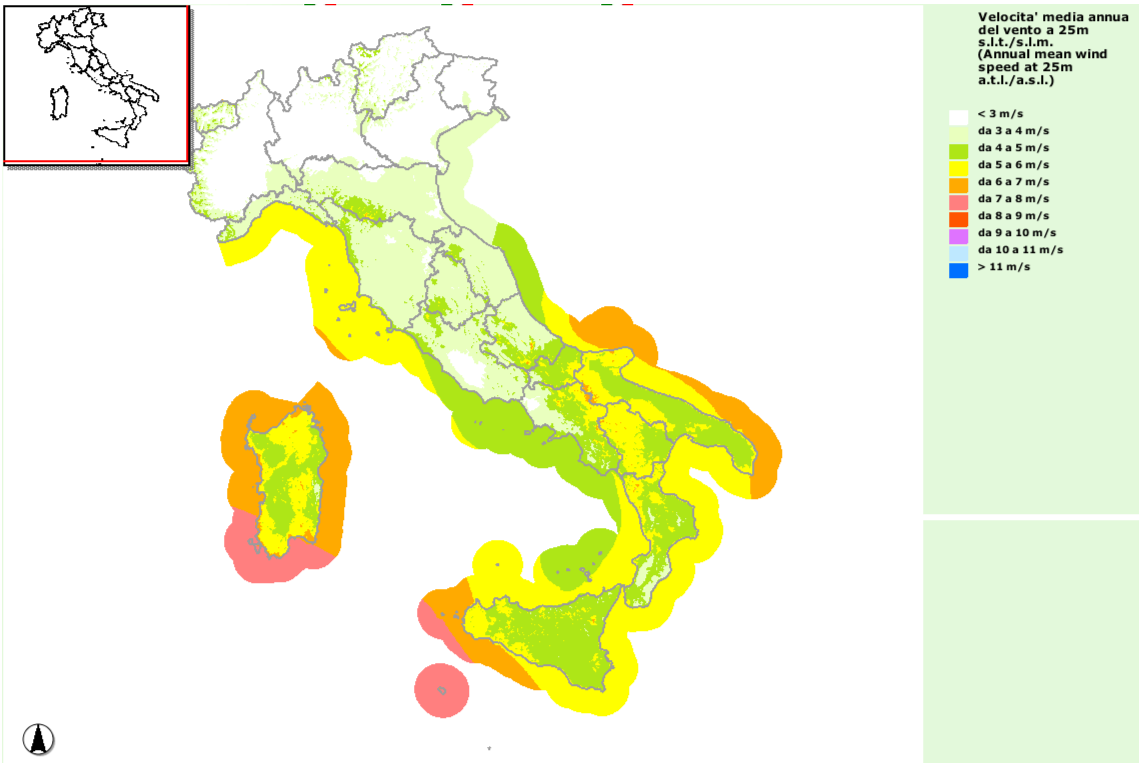

Figure 51: “Atlante Eolico Italiano” with annual average wind speed

Calculated the characteristic parameters of the wind speed in this way:

- the maximum value and the specific power associated to the percentage of the values of calm (with wind speeds less than 0.5 m/s);
- the specific energy that is a function of the direction of the wind in that period (for example, month) ;
- the statistical parameters related to the values obtained for the turbulence of the wind in the site.

In the case of multi-functional wind turbine, the selection of wind farm site will be made primarily based on the direction of the wind. In fact, we need to ensure a constant flow of the wind that comes from the north or northeast. This consideration has been made to ensure that the blade exposure to sunlight continually. Thanks to the data processed by existing stations it was possible to determine the exact position of the blade. The need to orient the blade to the east (where the sun rises), and in particular the need to have a good wind flow, allowed to assume a position of the blade in Messina. The blade will be positioned upwind towards the northeast, so will have a greater radiated surface throughout the day because it is oriented to the east. The choice of positioning the blade made possible thanks to the presence of wind data, provided by the “Istituto Superiore per la Protezione e la Ricerca Ambientale”. After a careful evaluation, with respect to the requirements dictated by the project, the choice fell on Messina. The location so will ensure a good flow path and at the same time a continuous radiation of the sun.

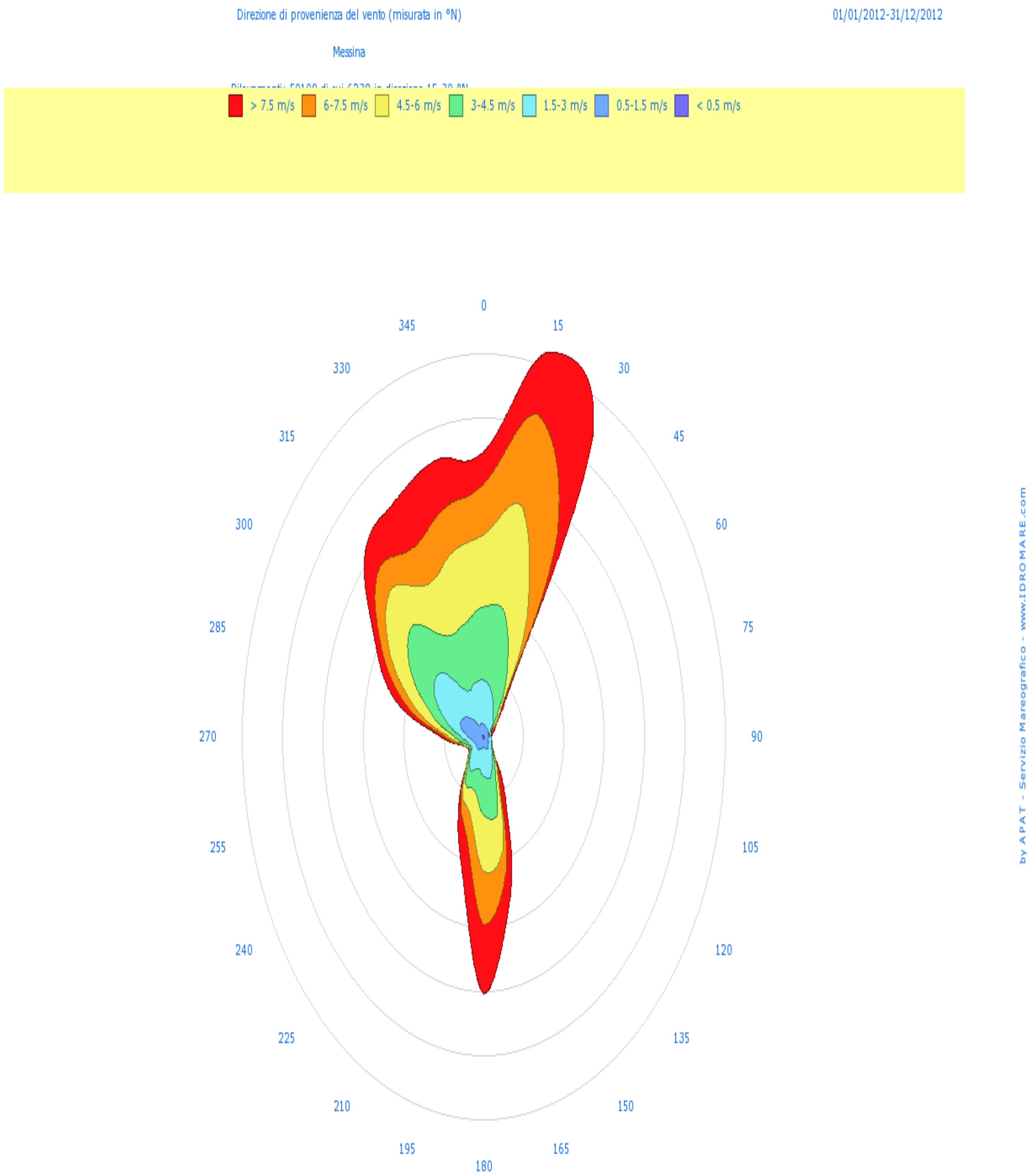

Figure 52: Direction of wind in Messina

The costs for the installation are around 1,5 million euro (for offshore installations should be considered an increase of at least 30%). These costs include all the steps necessary for the development of a wind farm:

- the initial step (site identification, micro-siting, anemological study, authorization procedures, agreements with landowners, etc.);
- the planning stages of the plant;
- the construction of the plant.

The factors that may have a more pronounced influence on costs are the choice of the wind turbines, accessibility to the site, the distance from the electricity transmission network and the technical characteristics of the same. The operating costs of the plant, including routine maintenance, insurance and other operating costs, estimated at around 3% per annum of the cost of installation and account for 20-25% of the cost of kWh produced over the entire lifetime of a turbine. This value is around 10-15% at the beginning of operations of the turbine and may be increased up to 30-35% towards the end of the life cycle. The items that fall in the costs of operation and maintenance are:

- insurance costs;
- ordinary maintenance costs;
- extraordinary maintenance costs (repairs and spare parts) ,
- administrative costs;
- cost of land lease;
- costs of electricity supply;
- miscellaneous costs.

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